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AN ECONOMETRIC STUDY OF AERIAL INTERDICTION IN SOUTHERN LAOS, 1--ETC(U)

MAY 77 H L GILSTER, R D DUCKWORTH

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AN ECONOMETRIC STUDY OF AERIAL INTERDICTION IN SOUTHERN LAOS 10 OCTOBER 1970-30 JUNE 1971

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This research report is presented as a competent treatment of the subject, worthy of publication. The United States Air Force Academy vouches for the quality of the research, without necessarily endorsing the opinions and conclusions of the author.

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This research report has been reviewed and is approved for publication.

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The purpose of this study is to gain insight into the use of air power in the interdiction campaign in southern Laos. Basic tools of economic analysis are used to evaluate the effectiveness of air resources employed in the Steel Tiger operating area, ~~from 10 October 1970 to 30 June 1971~~. The primary objective of the campaign--to reduce the amount of enemy supplies reaching South Vietnam and Cambodia--is used as the basic measure of strike sortie effectiveness. Southeast Asia variable cost factors are derived and used in conjunction with production functions estimated by the technique of regression analysis to derive optimal

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cost-effective sortie allocations. These allocations highlight the role of the gunship team in the interdiction effort and indicate fewer strike sorties against the enemy road network could have been flown to achieve the same level of effectiveness. Given the strike resources available, however, the variable cost of tactical air sorties actually flown was within five percent of the estimated least-cost optimum.

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CHAPTER I

INTRODUCTION

Purpose

The purpose of this study is to gain insight into the use of air power in the interdiction campaign in southern Laos. It does not address the relative worth of the conflict in Southeast Asia or the air interdiction campaigns in particular. U.S. Armed Forces were deployed by political decree to Southeast Asia, and given this circumstance, a primary mission of military leaders was to conduct the assigned operations as efficiently as possible. In a sense they faced the traditional economic problem of maximizing output for a given budget level, or conversely, minimizing the cost of a given level of output.

This report presents an economic analysis of the allocation of air resources in the Steel Tiger operating area of southern Laos for the period 10 October 1970 to 30 June 1971, a period which incorporates the Commando Hunt V campaign. The campaign was officially conducted between 10 October 1970 and 30 April 1971. Since enemy activity did not cease on 30 April and normally continued well into the wet season, data from the months of May and June were included both to enlarge the data base and to provide a more complete coverage.

Detailed descriptions of the Steel Tiger interdiction campaigns can be found in three reports, Commando Hunt I,[2] Commando Hunt III,[3] and Commando Hunt V,[4] prepared by the Directorate of Tactical Analysis,

Headquarters Seventh Air Force. Material in these reports provided the background upon which this analysis is based.

The primary objective of the Commando Hunt interdiction campaigns was to "reduce the flow of personnel and materiel into the Republic of Vietnam and Cambodia to the lowest possible level."[4] The secondary objective was to "make the enemy pay an increasingly greater cost for his efforts to dominate Southeast Asia."[4] The second objective essentially reinforced the primary objective. The amount of supplies destroyed along the trail network in southern Laos added to enemy costs and resulted in fewer supplies available to enemy forces in South Vietnam and Cambodia. There can be no question, though, that the essential mission of interdiction forces was to reduce the amount of supplies, either by destruction or through forced enemy logistics expenditure, to a level below that at which a sustained enemy offensive in the south could be maintained. This study therefore takes the reduction of enemy supplies reaching the borders of South Vietnam and Cambodia as the basis from which to measure the effectiveness of air power in the interdiction role.

The study outline is predicated on the basic elements of an economic analysis. These elements are (1) Objective, (2) Alternatives, (3) Costs, (4) Model, and (5) Criterion. Chapter I defines the objective variable and the alternatives or basic air resources that influence the objective. Chapter II discusses the variable cost of applying these resources with cost factors derived from Southeast Asia experience. Chapter III gives a description of the estimated interdiction model, which relates the strike resources to the objective. Then the criterion of attaining the desired objective at minimum cost is applied

in Chapter IV to determine optimal allocations of air resources. The final chapter outlines the primary factors underlying the increase in tactical air effectiveness over the previous campaign, and the appendices provide additional information on the methodology and statistics used in the body of the text.

Objective Variable

The quantitative measure of supplies reaching the borders of South Vietnam and Cambodia is "throughput." Throughput was calculated by intelligence analysts who combined the number of southbound sensor-detected truck movements, aircraft visual truck observations, and road and river watch team observations along the Lao exit routes. Duplicate counts were eliminated to obtain an estimate of the actual truckloads of southbound supplies that exited the system.

To determine whether a reduction of supplies took place in Laos, throughput must be considered relative to some base figure, or measure of what the enemy put into the system. This measure is an estimate of truckloads of input from North Vietnam. The number of trucks entering Laos through the passes from North Vietnam was calculated in the same manner as throughput. To this figure was added an estimate of equivalent truckloads of supplies that also enter Laos through the pipelines and via Waterway 7J west of the DMZ. Input through these sources, however, was fairly insignificant, comprising only 4.4 percent of the total estimated input during Commando Hunt V. Total input is an independent estimate and is in no way predicated on the amount of throughput calculated during any time period.

It would appear that a reasonable measure of the impact of interdiction forces on the enemy logistics system, whether it be through the

destruction of enemy supplies or his expenditure of resources to maintain and defend the system, would be the difference between input and throughput lagged by some appropriate period to account for the length of time supplies were in transit. The lagged structure of this system becomes important, then, not because one needs to pinpoint exact transit times, but because we must determine a reasonable time over which the supplies that exit the system during any time period were subject to air attack.

One method of dealing with this problem is to determine whether high enemy activity on the throughput routes during any week, t, corresponds to high activity on the input routes during the previous weeks. To examine this effect, the correlations between throughput during week t and input during previous weeks were analyzed for the campaign under investigation as well as for an equivalent period during the previous dry season campaign which incorporated Commando Hunt III. Table 1 contains the campaign correlations for the previous campaign.

TABLE 1

WEEKLY CORRELATIONS BETWEEN THROUGHPUT AND INPUT
November 1969-June 1970

	IP_t	IP_{t-1}	IP_{t-2}	IP_{t-3}	IP_{t-4}	IP_{t-5}
TP_t	.72	.68	.74	.84	.76	.58

The high correlation between throughput during week t and input during week t-3 indicates that the predominant transit time during that campaign was three weeks. This does not mean that an exact three-week

transit time was maintained throughout the campaign--certainly there was some variation about this figure. The area analysis described in Appendix A provides some insight into this variation and supports the view that the primary travel time was three weeks.

Table 2 presents the same correlations for the period October 1970 through June 1971 with lags up to ten weeks. The highest correlation is between throughput during week t and input during week t-6. In general, however, the correlations are weaker than those of the previous campaign with the indication that transit time may have been extended up to eight weeks at times, probably sometime during the Lam Son 719 ground incursion into Laos. The area analysis of Appendix A also supports these estimates.

TABLE 2

WEEKLY CORRELATIONS BETWEEN THROUGHPUT AND INPUT
October 1970-June 1971

	IP_t	IP_{t-1}	IP_{t-2}	IP_{t-3}	IP_{t-4}	IP_{t-5}
TP_t	.38	.42	.56	.57	.54	.63
		IP_{t-6}	IP_{t-7}	IP_{t-8}	IP_{t-9}	IP_{t-10}
TP_t		.70	.51	.64	.54	.50

The fact that the correlations of Table 2 are weaker than those of Table 1 and that the higher correlations are found at longer time lags suggests that the enemy was less able to maintain a definite logistics plan during the later campaign. As no other factors appear to have influenced the increased lag time, it seems that the initiative rested more with U.S. forces during the Commando Hunt V period.

This weekly correlation analysis between throughput and input indicates

that six weeks would be the most reasonable single time frame for use in evaluating the effect of air strikes on enemy supplies in transit. But because it is impossible to precisely measure when a truckload of supplies put into the system actually exited the system, we used a three-week average for input and throughput at each end of the six-week period. Figure 1 illustrates the construction of the objective variable.

Input in truckloads for the weeks t-7, t-6, and t-5 was averaged to provide an average input centered at week t-6. Throughput for weeks t-1, t, and t+1 was also averaged to calculate an average throughput centered at week t. This throughput is then subtracted from the input to form the objective variable which we call "the reduction in throughput." As can be seen in Figure 1, the moving average construction accounts for possible transit times of from four to eight weeks.

Figure 2 presents the profile of the objective variable over the campaign under investigation. Each point on the lower curve gives the difference between average input centered at week t-6 and average throughput centered at week t. The horizontal axis denotes the week of throughput. For reference, input at week t-6 is plotted on the upper curve. The difference between the curves is throughput at week t--the input that successfully transited the system during the time frame used in the study. The weekly average input and throughput for the campaign were 512 and 76 truckloads respectively, resulting in an average reduction of 436 truckloads.

Relative to the size of input, we desire the reduction in throughput to be as large as possible, for its value is an absolute measure of the impact of interdiction. Assuming the creation of no permanent stockpiles

THE OBJECTIVE VARIABLE

$$IP_{t-6} — TP_t$$

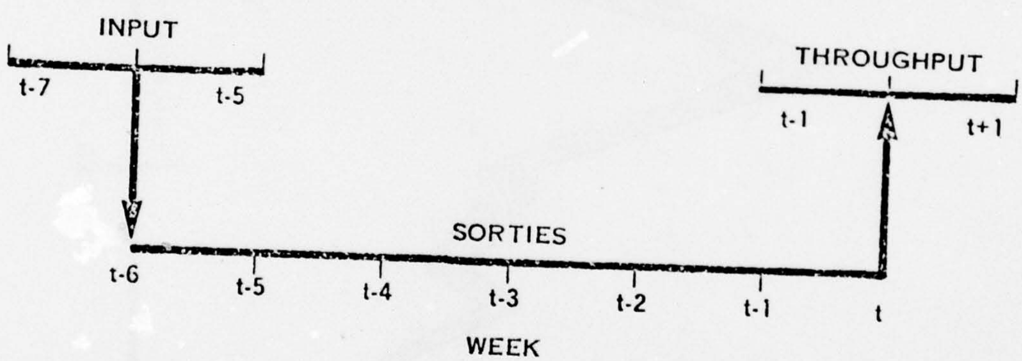


FIGURE 1

PROFILE OF THE OBJECTIVE VARIABLE

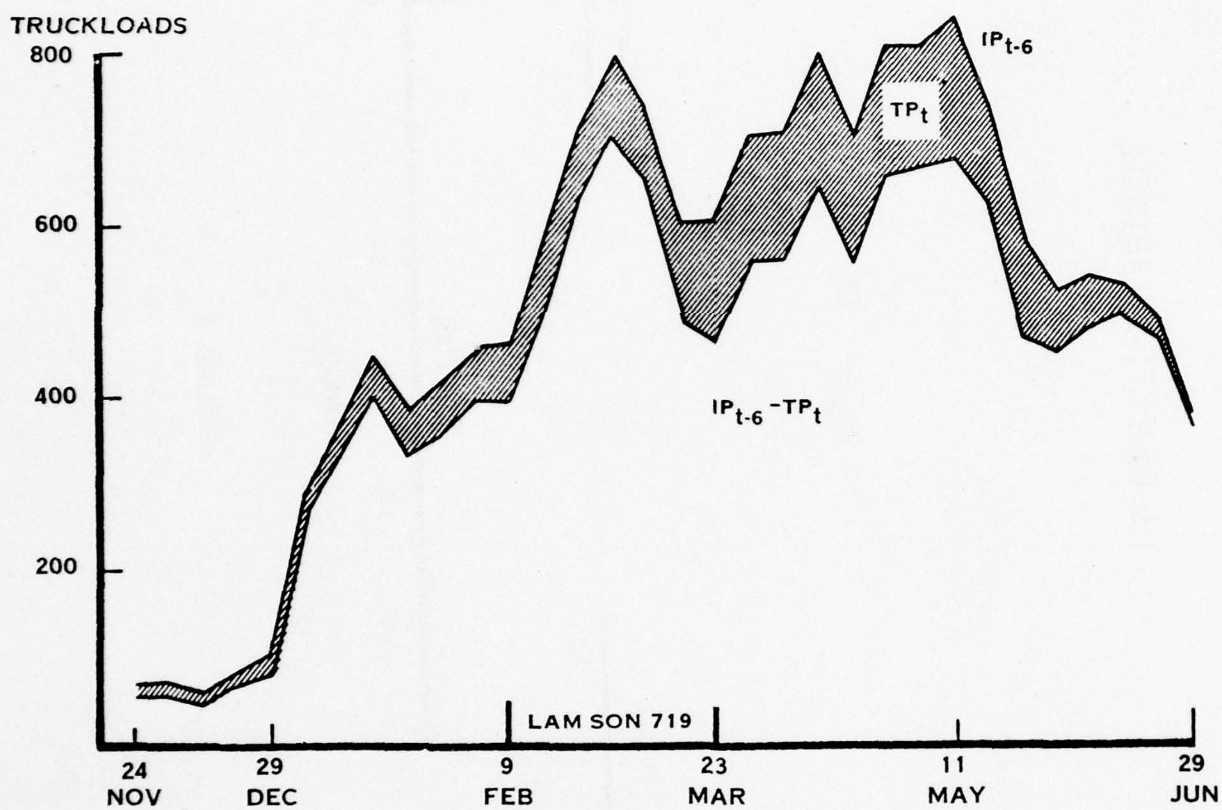


FIGURE 2

within the system, the difference between input and throughput can be attributed to interdiction forces, both air and ground. Some of the supplies put into the system did not exit the system during a reasonable time period. In this study, it matters not whether the volume of supplies was destroyed or expended in the maintenance and defense of the system. In either case, these supplies were not available to support enemy offensives in the south.

We therefore suggest that the objective variable described above is an appropriate measure with which to evaluate the effectiveness of air resources employed in the interdiction role. For any given input, it provides a quantitative measure of the reduction in supplies effected within the enemy's logistic system--the primary mission of the interdiction campaign.

It is interesting to note that the correlation coefficient between the objective variable and the estimated tonnage destroyed by air (bomb damage assessment,or BDA) is .87. BDA was estimated by intelligence analysts who applied standard tonnage factors to trucks reported[1] destroyed and damaged and to secondary fires and explosives not associated with truck kills. Even more highly correlated with the objective variable is the number of trucks reported as destroyed or damaged which has a value of .93. This latter correlation adds support to the creditability of reported truck kills and suggests that if there is a soft element in the BDA formula, it lies more with secondaries than truck kills. The strong relationship between trucks reported destroyed or damaged and a reduction in throughput is discussed in the final chapter.

Alternatives

We now describe the alternates available to the air commander which were employed to attain the objective. These alternatives consist of different possible combinations of sorties flown against the enemy's logistic system. Of primary interest are the strike sorties that deliver ordnance because they comprised 86 percent of the total variable cost of the interdiction campaign. The investigation therefore concentrates on the sorties listed by major aircraft type and target category in Table 3.

TABLE 3

STRIKE SORTIE VARIABLES

Aircraft Type	Target Category	Weekly Average Day	Night
Gunship (AC-130, AC-119K)	Trucks	. .	65
Fighter and Attack (F-4, F-100, A-1, A-4, A-6, A-7, B-57G)	Trucks	93	234
	Storage Areas	227	89
	Lines of Communication	487	208
	Enemy Defenses	59	131
	Close Air Support	277	68
		1123	750
Arc Light (B-52)	Storage Areas	35	26
	Lines of Communication	44	66
	Close Air Support	24	25
		103	117

These data were extracted on a weekly basis from the Southeast Asia Data Base which classifies sorties by the first target type they struck. During the course of a mission, some sorties did strike other targets, but, in general, most expended the ordnance on the same target type. This

classification scheme is consistent with that of the Commando Hunt reports and is continued in this study. To conform with the lagged structure described in the previous section and the assumption that six weeks was a reasonable period over which air strikes might affect a volume of supplies in transit, weekly averages from week t-6 through week t (see Figure 1) were calculated for each sortie type for use as the primary input or explanatory variables in the model described in Chapter III.

One additional explanatory variable that influenced the volume of throughput, but was not under full control of the air commander, is the enemy's intent to push a volume of supplies through during a particular time period. Since actual intent is unknown, some quantifiable proxy variable should be selected to approximate this effect. The variable most highly related to throughput is the number of southbound sensor-detected truck movements. If the enemy was very intent on increasing throughput during a particular period, we witnessed a greater number of southbound truck movements during that and the preceding time period. Southbound sensor-detected truck movements are therefore used as a normalizing influence to improve the statistical properties of the interdiction model described later in the study. A moving weekly average, identical to that used for sorties, was constructed for this purpose.

CHAPTER II

COST FACTORS

Methodology

When determining how to conduct tactical air operations in the most efficient manner, only the variable costs are relevant. The analysis should be limited to evaluating the utilization of those resources consumed in the actual performance of the mission. Costs that cannot be directly related to the operation or to any particular weapons system should be omitted. These costs are generally defined as fixed costs because they do not vary with the level of combat activity and they are not a direct consequence of flying the mission. Even so, the identification of appropriate wartime variable costs is no simple matter. (For a detailed discussion of these identification problems, see RAND Document D-20029-PR, Some Methodological Problems of Wartime Costing[8].)

The primary operational data used for computing costs in this study were extracted from the Commando Hunt V[4] report and the Southeast Asia Data Base. Other references and sources included Air Force Manual 172-3, Cost and Planning Factors;[1] USAF Nonnuclear Consumables, Volume II;[10] USAF Management Summary;[9] RAND Memorandum RM-6238-PR, Recce-Strike Systems for Attacking Moving Trucks;[7] and the Seventh Air Force Budget. All of these sources were used to cross-check the final cost information that was assembled.

Listed below are the main cost factors used to derive the variable sortie costs used in this study:

Combat Aircraft Attrition Cost
Combat Aircrew Attrition Cost
Munitions Cost
Variable Operating Cost
- Fuel and Oil
- Depot Maintenance
- Base Maintenance
- Replenishment Spares

The list is certainly not complete, but it does contain the major expense items that constitute the cost of flying a sortie in a combat environment.

Combat Aircraft Attrition

An important and unique cost in this analysis was the loss of an aircraft under combat conditions. Between 10 October 1970 and 30 June 1971, twenty-nine fixed-wing aircraft were lost in combat over southern Laos. This does not include operational losses because these losses would also be experienced in a peacetime environment.

Assigning costs to combat losses, however, is a difficult task since these costs depend on the aircraft replacement policy prevailing at the time of loss. A weapons system is procured to obtain combat capability, and if an aircraft is lost, capability is reduced. This capability degradation is difficult to translate into dollars, but a measure of this cost is the cost of the replacement aircraft. Even though the attrited aircraft may be scheduled for retirement in the near future, there is a loss resulting from a reduction in capability of

the inactive inventory. This loss must be added to the immediate reduction in the present capability to carry out the tactical operation.

The analyst faces several options. If the aircraft is not replaced, the replacement cost is zero. If the aircraft is replaced one-for-one with an identical aircraft (including later model aircraft) procured as a consequence of the combat loss, the cost of attrition is the replacement flyaway cost. A final option is to replace the lost aircraft with a new type aircraft. If this is done, a prorated share of the non-recurring costs (i.e., initial spares, AGE, and initial training) should be added to the aircraft flyaway cost. Since no definite information was available on replacement policies for aircraft lost in Southeast Asia, the cost of an identical aircraft was used unless a newer model was being procured. In this case the cost of the new model was used in lieu of the cost of the earlier airframe no longer in production. The cumulative average unit costs specified in AFM 172-3 were attached as the cost of most aircraft. Several aircraft costs, such as that for the AC-130 and the B-57G, were estimated from RAND sources listing the costs of the like-configured models or from Air Force sources listing the total costs of the modification programs.

To compute the aircraft attrition rate per sortie, the total number of each type aircraft lost during the campaign was divided by the total number of sorties. As an example, five F-4s were lost in combat on strike missions. Dividing 5 by 28,437 (total F-4 strike sorties flown) gave an attrition rate of .000175, or about .18 per 1000 sorties. Multiplying this attrition rate by the F-4E procurement Fiscal Year 1972 cost of 3.6 million dollars gave an F-4 attrition cost per strike sortie of $630.

Attrition costs for all sorties were calculated in the same manner and are included in Table E-2, Appendix E.

Combat Aircrew Attrition

The rationale for including the cost of training new crews to replace those lost is similar to the combat capability argument made above; that is, unless replaced, combat-lost aircrews constitute a loss of capability and the appropriate cost is the cost to replace that capability.

During the campaign, approximately 41 percent of the total number of crew members shot down were not recovered. Detailed data were available on the crew status of nearly every combat aircraft loss, and this data facilitated the computation of exact crew attrition rates for each aircraft type and mission flown. For example, the F-4 aircraft strike crew attrition rate was .000070 since only two crews were not recovered from the five strike F-4s lost during the campaign. Aircrew attrition rates are also included in Table E-2, Appendix E.

While the cost of human lives from aircrew attrition is hardly measurable in monetary terms, an associated quantifiable cost consists of death benefits for those lost plus the training cost for replacements. RAND analysts have estimated death benefits and the average replacement training cost to be $250,000 for officers[8]. This factor was derived by using an estimate for death benefits of $20,000 per man added to a weighted average of the costs of various pilot training programs outlined in AFM 172-3. Since the costs are likely to be similar for all services, this same factor was used for Navy and Marine officers. An estimated cost of $50,000 was calculated for enlisted crew members lost in transport and helicopter aircraft to cover death benefits and flight engineer training

costs; however, no enlisted crew members were lost in this campaign.

Munitions Cost

The cost of the ordnance expended during the campaign comprised the major portion of the total variable cost of the operation. The cost of this ordnance included both the purchase price and the cost of transportation to Southeast Asia.

The procedure used to compute total ordnance cost relied upon a number of cross-checks to verify the validity of the approach taken. Individual ordnance expended by aircraft type and base during the campaign was obtained from the Southeast Asia Data Base. Each item was assigned a cost to arrive at the total cost of ordnance expended. This total cost was then divided by the number of sorties flown by each strike aircraft to calculate an average ordnance cost per sortie.

A check was made of these statistical averages by tasking the Directorate of Combat Operations, Headquarters, Seventh Air Force, to specify the typical ordnance load delivered by each of the strike aircraft. The PACAF Airmunition Planning and Program Guide[6] was helpful in cross-checking these typical ordnance loads. The loads were then given a dollar value and compared to the statistical averages cited above. The resulting cost factors showed variations of no more than a few percentage points.

These factors did not include the cost of transporting ordnance to Southeast Asia. RAND analysts have estimated the transportation cost to be $200 to $400 per ton, while the Office of the Assistant Chief of Staff, Studies and Analysis, recommended a value of $100 per bomb. Because the data were in numbers of bombs expended rather than in tons, the latter figure was selected. Based on the amount of ordnance expended and the

total number of strike sorties flown, $860 was added to the cost of each strike sortie to cover the transportation cost of the ordnance. The Arc Light missions were costed separately to cover the 590,846 bombs the B-52s dropped during the period. The average ordnance cost per sortie for all strike aircraft are listed in Table E-1, Appendix E.

Variable Operating Costs

Variable operating costs normally are composed of costs associated with the day-to-day operation of the mission. The USAF Management Summary defines and specifies these cost factors which include fuel and oil, depot maintenance, base maintenance, and replenishment spare costs extracted from AFM 172-3. However, these peacetime operating costs are not always appropriate for a combat environment. Therefore, additional research into the variable cost factors was necessary to derive valid estimates for use in this study. In general, the figures used were taken directly from tables in AFM 172-3; however, based on actual flying hours, the POL figures were increased to reflect the cost experience in Southeast Asia. The specific costs used in this study are presented in Table E-3, Appendix E. Several special aircraft, such as the B-57G and the AC-130 had operating costs that were estimated from various other sources (see footnote to Table E-3, Appendix E). A sortie cost was calculated by multiplying the cost per flying hour by the average sortie time flown by each aircraft type. The variable operating cost per sortie was then added to the attrition and ordnance costs to arrive at the total variable cost per sortie listed in Table E-1, Appendix E.

Variable Cost of the Interdiction Campaign

The cost discussion above outlined a number of theoretical and practical problems associated with identifying the estimated variable cost of a combat operation. These problems imply that a wide range of alternative assumptions had to be considered. However, the choices made in this study suggest that the approximate variable cost of nearly 9 months of interdiction operations was $1,081 million or about $4.1 million a day. These costs are summarized by mission type in Table 4 and appear reasonable when compared to those of other studies covering interdiction campaigns.

TABLE 4

TOTAL VARIABLE COST OF THE INTERDICTION CAMPAIGN
(10 October 1970-30 June 1971)

Mission	Total Sorties		Average Cost/Sortie		Total Variable Cost (Millions)	
All Fighter/Attack						
Fighter/Attack	60,900		$ 8,750		$532.9	
B-57G	1,600		15,600		25.0	
		62,500		8,900		557.9
Gunship Team						
Gunships	3,000		11,500		34.4	
F-4 Escorts	6,300		13,600		85.0	
		9,300		52,300		119.4
Arc Light		7,800		32,500		253.3
Total Strike		79,600				930.6 (86%)
Total Support		49,200		3,100		150.5 (14%)
Campaign Total		128.800				$1,081.1 (100%)
Sorties/Day		490		Cost/Day		$4.1

The average cost per sortie for fighter and attack aircraft of $8,900 is an average, weighted by the number of sorties flown by all fighter and

attack aircraft, including the B-57, during the campaign. It does not include the F-4 aircraft that escorted gunships since these aircraft were considered an integral part of the gunship team, another weapons system category. The gunship sortie cost was also an average,weighted by the number of sorties flown by the AC-130 and AC-119K aircraft. The cost of the F-4 escort sortie was higher than the fighter and attack aircraft average because the F-4 is a more expensive aircraft to operate and carried a large ordnance load consisting primarily of high-cost flak suppression munitions. Also,two escorts were shot down during the campaign, doubling the attrition cost per sortie over that of other F-4 strike missions. The total variable cost of the gunship sortie with its three escorts was therefore estimated to be $52,300. The cost of an Arc Light (B-52) sortie was estimated to be $32,500. If a prorated share of its protective package, which consisted of an ELINT (B-66) with fighter and attack Ironhand and MIGCAPS, were included, the total variable cost of an Arc Light sortie would be $34,200.

It is interesting to note that over 86 percent of the total cost of the campaign was incurred by the strike aircraft. Approximately 80 percent of this amount can be attributed to ordnance and attrition costs, costs unique to the combat operation. If cost reductions are desired, it appears that the most lucrative area for research are the costs of the strike aircraft. Therefore, the economic analysis that follows concentrates on this segment of the operation.

CHAPTER III

THE INTERDICTION MODEL

Estimation of the Model

At the heart of an economic analysis is a model. The model describes how inputs can be combined to produce the output or objective. Numerous specifications were tested, and the one that provided the most significant and realistic results was the modified version of the Cobb-Douglas production function given below:

$$Y = X_1^{B_1} X_2^{B_2} X_3^{B_3} X_4^{B_4} X_5^{B_5} .$$

The output, or objective variable in this context, is the difference in truckloads between input at week t-6 (IP_{t-6}) and throughput at week t (TP_t) described in Chapter I. The explanatory or input variables, the Xs, with the exception of X_5, are the sorties by target type that contributed to the reduction in throughput. X_5 is southbound sensor-detected truck movements used to proxy the enemy intent. The Bs are the parameters of the model that are estimated by the technique of regression analysis.

The model is an exponential or multiplicate model which incorporates the interaction between the various sortie types and enemy intent to produce the desired output. In this sense it appears more intuitively realistic than a straight linear model which implies that the contribution of the various inputs are independent and additive. This judgment was validated when the parameters of a linear additive model were found to be statistically insignificant.

To estimate the values of the parameters, Bs, it is necessary to

transform the model so that the parameters become linear functions of the dependent variable, Y. This is easily accomplished by using the natural logarithmic (Ln) form of the equation:

$$LnY = B_1LnX_1 + B_2LnX_2 + B_3LnX_3 + B_4LnX_4 + B_5LnX_5 \; .$$

Before estimating the model, a further refinement was made by normalizing the variables by LnX_5, the natural logarithm of southbound sensor-detected truck movements. This procedure improved the statistical properties of the estimated parameters and does have a precedent in econometrics, particularly for investment functions where the size of the firm is used to normalize the data in a sample that incorporates both large and small firms. It is considered appropriate here because the volume of enemy activity varied considerably over the campaign from 10 October 1970 to 30 June 1971, and strike effectiveness is greater in a target-rich environment. Appendix B provides the rationale for this estimating technique and describes additional results from other specifications of the model.

The form of the model estimated was

$$\frac{LnY}{LnX_5} = B_1 \frac{LnX_1}{LnX_5} + B_2 \frac{LnX_2}{LnX_5} + B_3 \frac{LnX_3}{LnX_5} + B_4 \frac{LnX_4}{LnX_5} + B_5 \; .$$

The Bs are estimated directly and can be used in the original exponential form. B_5, the constant in the model actually estimated, is the exponent of the variable, southbound sensor-detected truck movements.

The estimated parameters for the tactical air sorties flown by gunships and fighter and attack aircraft are presented in Table 5. The parameters were estimated using 32 data points, or weekly average observations to cover the period of the campaign. The equation accounts for 86 percent

of the variation in the dependent variable, $IP_{t-6} - TP_t$, and the T ratios for the exponents of the explanatory variables, or sortie types, are all significant at the 95 percent confidence level.

TABLE 5

ESTIMATED INTERDICTION MODEL PARAMETERS

Tactical Air Sorties	B	T ratio
Gunship	1.30699	5.32
Trucks and Storage Areas	.57201	2.45
Lines of Communication	.33317	2.01
Close Air Support	.27748	2.26

Constant term = -.84535 R^2 = .86

Explanation of the Model

Transforming the logarithmic model back into the original exponential form provides the following equation:

$$Y = X_1^{1.31} X_2^{.57} X_3^{.33} X_4^{.28} X_5^{-.85}$$

where: Y = The objective variable, $IP_{t-6} - TP_t$

X_1 = Gunship team sorties against trucks per week

X_2 = Fighter and attack sorties against trucks and storage areas per week

X_3 = Fighter and attack sorties against lines of communication per week

X_4 = Fighter and attack sorties in close air support per week.

All Xs are weekly averages from week t-6 through week t.

The major categories into which sorties were grouped requires further explanation and is given below. Take first the gunship team concept. The gunships, AC-130s and AC-119Ks, normally operated at night against trucks

with three F-4 escort aircraft. An analysis of the data base indicated that on average approximately two of the escorts expended against enemy defenses in a flak suppression role and that the correlation between gunship sorties and night defense sorties was .97. The other escort predominantly expended against enemy trucks in conjunction with the gunship, again with a very high correlation. Therefore, for both statistical and operational reasons, these sorties were considered a part of the gunship team, and the gunship sortie was taken as a proxy in the study for this very effective team concept.

The exponent of 1.31 on the gunship team variable is greater than one and requires some explanation because it indicates that as more gunship sorties were flown, effectiveness increased at an increasing rate. A one percent increase in gunship sorties resulted in a more than one percent increase in the objective variable. Two explanations seem plausible. One is that as the campaign began, few gunships were available and the crews were inexperienced. As the campaign progressed, more gunships were made available to Southeast Asia at the same time the crews were gaining valuable experience. The exponent may, therefore, incorporate a crew learning curve, but it was not possible to break this out statistically.

Another explanation may be that as the gunship force increased, alternative routes the enemy previously used could be covered. This is analogous to the example used to explain increasing returns to the last few radars that close a gap in the Dew Line. As long as a gap remains through which the enemy may strike, the Dew Line is partially ineffective. But as the gap is closed, the whole system becomes effective, and we receive high returns to the last few radars that secure the system. The extent

to which these returns would be further experienced in the gunship case, however, is subject to question. The largest number of gunship sorties against trucks that were available during the campaign was approximately 100. To extend the analysis beyond the data base may be invalid because beyond some point,we could experience diminishing returns as the force is increased, especially if space limitation becomes critical.

Next, the fighter and attack sorties, including the B-57s, against trucks and storage areas were also grouped for two reasons. The first was statistical. When these sorties are not segregated by day and night, they tend to move together. During the beginning and end of the dry season campaigns,a large number of the sorties were directed against the enemy's road network, or lines of communication. During mid-campaign, when the enemy surge occurred, more sorties were directed against the supplies on trucks and in storage areas. The correlation between truck and storage area sorties, .94, makes it difficult to break out their individual influence with any degree of confidence. The second reason for grouping these sorties was operational. A majority of these sorties were not scheduled to specific targets but were assigned to the Airborne Battlefield Command and Control Center (ABCCC) and forward air controllers (FACs) to be directed against the most lucrative targets whether they were trucks or storage areas. This control feature complicates the stratification process and indicates that these sorties should be viewed as an entity.

The third set of sorties were those directed against the enemy's lines of communication (LOCs). The controversy surrounding the use of sorties against the enemy road network and the fact that they were more

centrally scheduled indicates that they should be treated separately in the model. An evaluation of this set of sorties during an equivalent Commando Hunt III period questioned their effectiveness. During the period of the present investigation, they did appear productive but at a lower level than the first two categories described.

The final sortie category in the model is fighter and attack sorties flown in close air support of ground operations. A vast majority of these sorties were flown during the Lam Son 719 ground incursion into Laos. In addition, an evaluation of the data base revealed that a large majority of the sorties flown against enemy defenses during the daytime were employed in a flak suppression role during Lam Son 719. The correlation between these sorties and the sorties flown in close air support of ground operations was .98. The day sorties against enemy defenses were therefore added to the close air support sorties as a vital ingredient of that operation. Close air support is not normally viewed as a function of air interdiction forces which operate at a distance behind enemy lines. During Commando V, however, the Lam Son 719 incursion into Laos played a vital role in the interdiction campaign, for its purpose was not to gain and hold enemy territory, but to disrupt the enemy's lines of communication and destroy his supplies. As such, the sorties in support of this operation contributed to the interdiction mission--the reduction in supplies reaching South Vietnam and Cambodia.

The last variable in the model, southbound sensor-detected truck movements, acts as a proxy for enemy intent. The exponent is negative, which indicates that if sortie levels are held constant, and southbound enemy activity increases, the difference between input and throughput

will decrease. In other words, if sortie levels are not increased when enemy activity increases, throughput for any given amount of input will increase. The absolute value of the exponent, .85, is less than one, however, which implies that a one percent increase in southbound sensor-detected truck movements resulted in less than a one percent decrease in our ability to reduce throughput. In general, a given force is more effective in a target-rich environment. As explained previously, the air commander does not have full control over this variable,and its main purpose in the model was to hold the level of enemy activity constant so that the effectiveness of air resources could be evaluated.

So far no mention has been made of the Arc Light (B-52) sorties flown in conjunction with tactical air sorties during the campaign. In general, the high correlations with tactical air sorties made it impossible to break out their separate effects, although a rather significant relationship did exist between the objective variable and those Arc Light sorties flown in support of Lam Son 719. This could indicate that Arc Light is most effective when used against troop and supply concentrations. In addition, it could well be that the use of Arc Light in conjunction with tactical air sorties against enemy LOCs resulted in the positive contribution of LOC sorties that was not evident in analyses of previous campaigns.

High correlations prevented the incorporation of all tactical air and Arc Light sortie categories in the same model,and rather than delete various categories of each, we decided to restrict the study to an evaluation of a pure tactical air model that encompassed all gunship team and fighter and attack sorties. These sorties were under direct control of

the Commander, Seventh Air Force, whereas Arc Light sorties were partially controlled through another command channel.

The interdiction model, therefore, specifies how the various tactical air sorties can be combined to attain the given objective. Since it is a continuous function, there are nearly an infinite number of alternate sortie combinations that will serve this purpose. In Chapter IV a criterion is established to determine which, out of all the possible alternatives, is the most cost-effective.

Graphical Presentation of the Model

The estimated interdiction model described above defines a six-dimensional hypersurface which is impossible to visualize. The individual influence of a particular sortie type can be visualized, however, by holding the numbers of the other sorties constant at some values, such as their means, and calculating the change in the objective variable as the number of sorties in the selected category is varied. These two-dimensional relationships are plotted in Figure 3 with southbound sensor-detected truck movements also held constant at the mean campaign value of 3312. Given also are the means and standard deviations for each sortie type to indicate the range of the curves in which the aircraft primarily operated.

The slopes of the lines denote the marginal products of the various sortie types at any sortie level and are the relevant values to be compared. Except for the gunship team, diminishing returns are experienced as each sortie type is increased with the others held constant. Of particular note is the high marginal product of the gunship team sortie

EFFECTS OF SORTIES ON THE OBJECTIVE

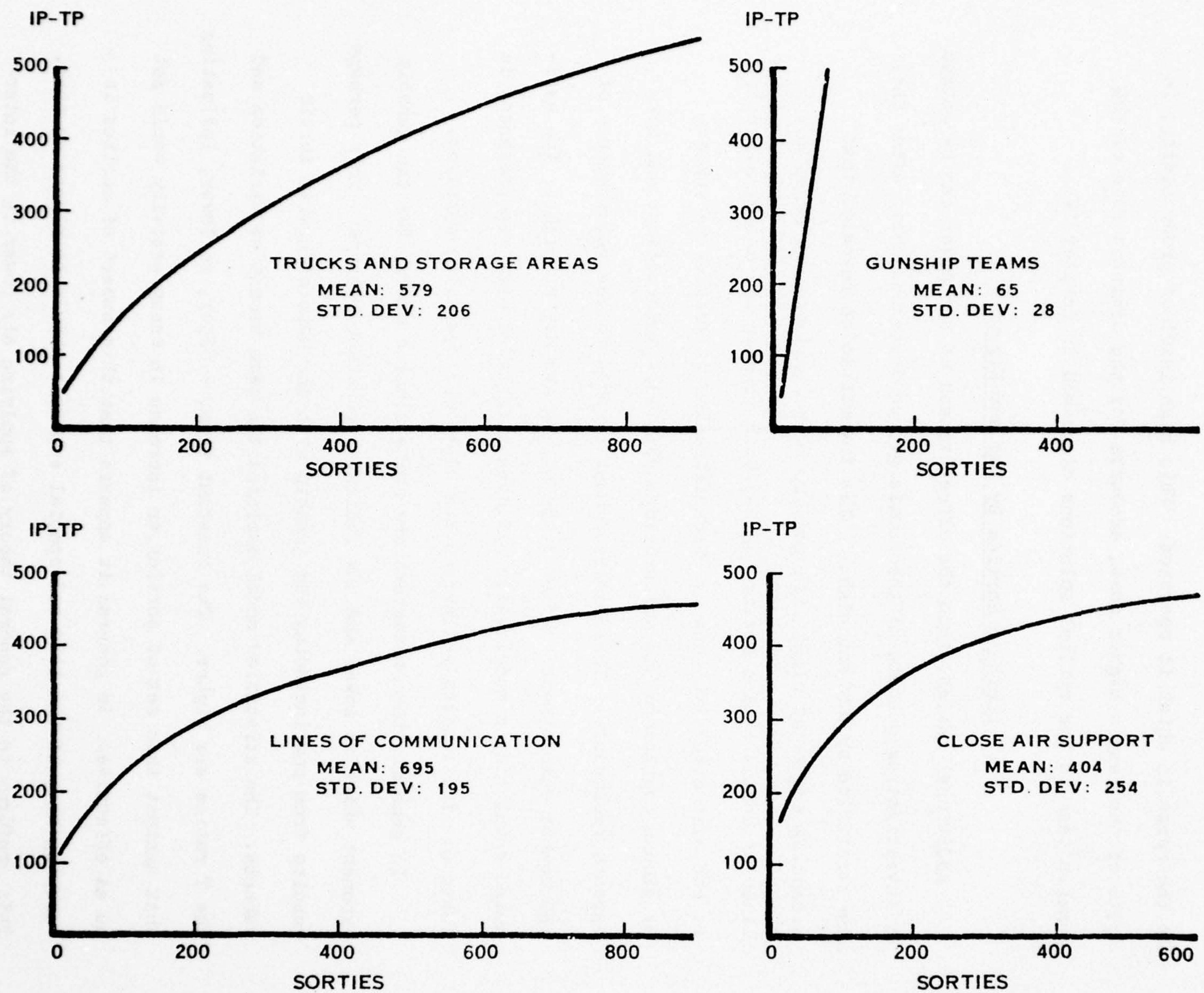


FIGURE 3

in the range in which it operated. This high level of productivity, in spite of the team's higher cost, accounts for the dominant role of the gunship team in the optimal solutions discussed in Chapter IV.

Dominant Sorties by Day and Night

Additional insight into the effectiveness of air power can be gained by investigating subsets of the sortie groups described above after they are stratified by day and night. This investigation revealed that attacking trucks at night with gunship teams, and storage areas and lines of communication during the day with fighter and attack aircraft is the most effective tactic. Stratification of sorties in support of ground operations did not provide additional information, and this appears reasonable. These sorties must respond to the requirements of the combat environment whether it be during the day or night. The estimated results of a model which utilized stratified data are presented in Table 6. The results in Table 5 are also included for comparison.

In general, the parameters are quite similar except for the gunship exponent which is lower and now indicates constant returns. This perhaps results from now including the gunship with the more effective sortie subsets. The stratified model explains the same amount of variation and the T ratios are higher. The constant term, -.62341, is lower, indicating that against this set of sorties, an increase in enemy activity would not be as effective. In general, it appears that this subset of sorties is carrying most of the load and special emphasis should be placed on them. This conforms to the general theory of applying air power in the interdiction role--striking trucks at night with gunship teams and storage

areas and LOCs during the daytime. During the campaign under investigation 72 percent of the storage area sorties and 70 percent of the LOC sorties struck during the daytime.

TABLE 6

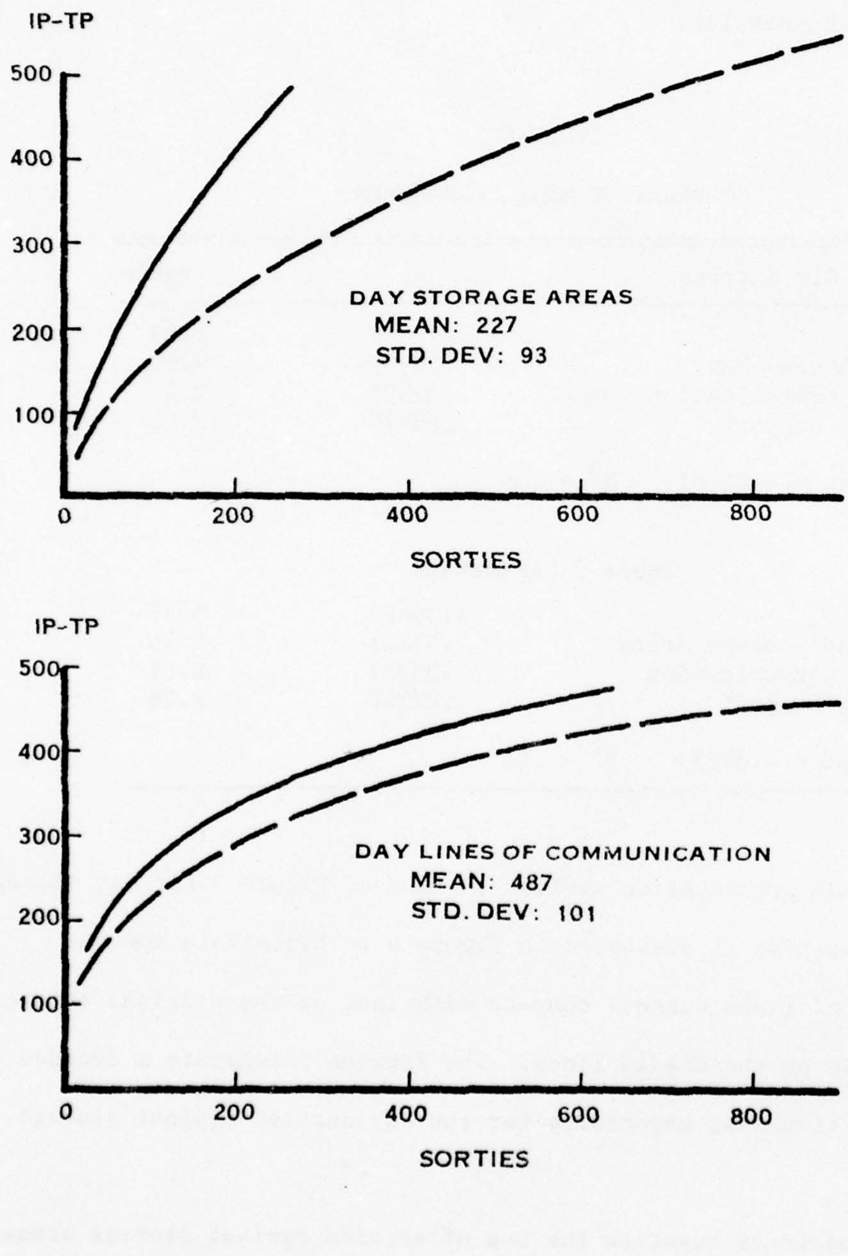
COMPARATIVE MODEL PARAMETERS

Tactical Air Sorties	B	T ratio
Gunship	.99476	6.69
Storage Areas--Day	.60739	4.08
Lines of Communication--Day	.32093	3.45
Close Air Support	.28476	2.98
Constant = -.62341 R^2 = .86		
Table 5 Parameters		
Gunship	1.30699	5.32
Trucks and Storage Areas	.57201	2.45
Lines of Communication	.33317	2.01
Close Air Support	.27748	2.26
Constant = -.84535 R^2 = .86		

A graphical presentation similar to that of Figure 3 for day storage area and LOC sorties is presented in Figure 4 to illustrate how the effectiveness of these subsets compare with that of the original categories which are shown by the dashed lines. The figures illustrate a decided shift in effectiveness, especially for the day sorties against storage areas.

Some authorities question the use of sorties against storage areas because they are widely dispersed and, with the lack of intelligence, difficult to discover. The effectiveness of these sorties, however, must be evaluated in light of the Commando Hunt V experience. The sorties

EFFECTS OF DAY STORAGE AREA AND LINES OF COMMUNICATION SORTIES



used to estimate the parameters of the model were not those that flew in search of storage areas but those which actually struck these areas. Several spectacular strikes were experienced during the Commando Hunt V campaign in which numerous secondary explosions were experienced. It appears that the appropriate tactic is the probing technique initiated during the campaign. Then, when promising results are revealed, a large number of sorties are immediately scheduled to take advantage of the discovery. It could also be that a number of the sorties that were unable to observe the results of their strikes were actually effecting some damage that was reflected in a reduction in throughput.

In conclusion, it might be noted that it would be operationally infeasible to schedule only gunship team sorties to strike trucks at night and fighter and attack sorties to strike storage areas and LOCs during the day. Additional coverage is required, but these statistical results do indicate where the emphasis should lie.

CHAPTER IV

AN ECONOMIC EVALUATION OF SORTIE ALLOCATIONS

The Criterion

Up to this point four of the basic elements of an economic analysis have been examined. The objective and alternatives have been defined, the costs of applying air resources have been calculated, and the interdiction model which relates the inputs to the objective has been estimated. To complete the analysis and compute an optimal allocation of tactical air resources in terms of the Commando Hunt V experience, the costs and marginal contribution of the various sortie types must be brought together and a criterion established.

Since sorties and the objective variable are not expressed in the same units, the concept of constrained optimization must be employed. It is impossible to simultaneously maximize output and minimize costs. Maximizing output would call for a prohibitively large force, while minimizing cost would call for no force at all. These dual criteria are therefore incompatible. As a proper criterion, we may either minimize the cost of attaining a given output or, conversely, maximize output for a given resource or cost level. These are actually two sides of the same coin, and both provide the same optimal trade-offs between the various sortie types. The particular approach employed depends on which of the two criteria are selected. Because of the interest in reducing the cost of operations in Southeast Asia, the former approach will form the basis of the economic analysis that follows. An example of maximizing output for a given resource level, however, will also be provided.

by the sorties flown by the AC-130 and AC-119K gunships, each escorted by three F-4 aircraft expending ordnance in support of the gunship.

The solution to this constrained optimization problem is obtained by minimizing the following Lagrange function:

$$L = P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 - M_1\ (A\ X_1^{B_1}X_2^{B_2}X_3^{B_3}X_4^{B_4} - C)$$

where M_1 is the Lagrange multiplier. In economic terms M_1 is a shadow price, or more specifically, the marginal cost of attaining a reduction in throughput by one truckload at the optimum. This function is minimized by taking the partial derivatives with respect to each variable and setting each partial derivative equal to zero. This provides five equations which can be solved to obtain the value of the five unknowns (X_1, X_2, X_3, X_4, and M_1). The exact technique employed is described in Appendix C.

Because of the high productivity of the gunship teams, the solution called for more gunship team sorties than were available to strike trucks at night during the time period under consideration. For this reason, a second constraint was employed to arrive at a realistic solution. Optimum number 2 was therefore obtained by using the following specification:

Minimize: The cost of sorties flown

Subject to: (1) $IP_{t-6} - TP_t = 436$ truckloads per week

(2) Gunship sorties = 65 per week (Oct 70-Jun 71 average).

The Lagrange function to be minimized then becomes (see Appendix C):

$$L = P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 - M_1\ (AX_1^{B_1}X_2^{B_2}X_3^{B_3}X_4^{B_4} - C) - M_2\ (X_1 - S_1)$$

where S_1 is the number of gunship team sorties flown, and M_2 is the marginal value of a gunship team sortie at the optimum. The relevance of the Ms

will be explained when the solution is discussed. For those acquainted with isoquant-isocost diagrams, a graphical presentation of the methodology is presented in Appendix D.

Least-Cost Sortie Allocations

The numerical solutions to the cost minimization problems being addressed are given in Table 7. Also given, in the column entitled "Flown" are the weekly average number of sorties that flew and expended ordnance during the period October 1970 through June 1971. The total variable cost for this combination of sorties, based on the cost factors cited above, was approximately $18.3 million per week.

TABLE 7

WEEKLY SORTIE DISTRIBUTIONS TO REDUCE THROUGHPUT 436 TRUCKLOADS

Sortie Type	Flown	Optimum 1	Optimum 2
Gunship Teams	65	134	65
Fighter and Attack			
Trucks and Storage Areas	579	344	765
Lines of Communications	695	201	445
Close Air Support	404	167	371
Total	1678	712	1581
Cost per Week	$18,333,700	$13,345,000	$17,470,400
Savings per Week		4,988,700	863,300
Marginal Cost to Reduce Throughput		12,300	27,300
Marginal Value of a Gunship Team Sortie			187,000

Potential Reduction in Throughput Using Sorties Flown = 467 Truckloads

The next column gives the first optimal solution in which the number of gunship team sorties was not constrained. This sortie combination would have cost about 13.3 million dollars per week and would have attained, according to the interdiction model, the same reduction in

throughput. It would entail a savings of approximately $5 million a week. The cost of attaining an additional reduction in throughput by one truckload at the optimum (the value of the Lagrange multiplier M_1) would be $12,300.

This solution, however, called for a weekly average 134 gunship team sorties to be flown at night against trucks in the Steel Tiger operating area. Due to the low number of gunships available at the start of the campaign and commitments to other operating areas and targets in Southeast Asia, this weekly average was infeasible for the whole campaign. It should also be kept in mind that this large number calls for an extension of the gunship team relationship to a point beyond the data base range used in estimating the model, so the relationship may or may not be valid at that point.

The second solution provides a more realistic optimum by constraining the number of gunship team sorties to 65, the weekly average flown during the period covered by this study. This solution requires 1581 fighter and attack sorties and is invariant with respect to their cost. In general, about 100 sorties are saved by shifting some sorties from LOC strikes to the more productive strikes against trucks and storage areas. The cost of the Optimum 2 combination of sorties is about $17.5 million, or a weekly savings of less than $1 million.

The critical role of the gunship team is highlighted in the second solution by the increased cost of obtaining a reduction in throughput by one truckload. As less effective weapons systems are substituted for the gunship team, it costs about twice as much to obtain the same reduction in throughput. The value of an additional gunship team sortie in the

second solution (the value of the Lagrange multiplier M_2) is \$187,000. This means that an additional gunship team sortie is worth \$187,000 more than it costs when only 65 are available. This marginal value decreases as more gunship team sorties become available and the first optimum is approached. These results, however, are indicative of the high opportunity cost of using gunship teams in functions other than striking trucks at night in the primary interdiction area.

A second way of looking at the optimal allocation scheme is to determine the reduction in throughput that could be expected from the sorties actually flown (see Appendix C). In other words, we now require to:

Maximize: The reduction in throughput ($IP_{t-6} - TP_t$)

Subject to: (1) Gunship team sorties = 65 per week

(2) Fighter and attack sorties = 1678 per week.

As shown in Table 7, the potential reduction is 467 truckloads, 31 truckloads more than was actually attained. If the sorties actually flown were optimally distributed, the throughput/input ratio would be .09, compared to the .15 ratio actually experienced from October 1970 through June 1971.

As a summary, the cost results of Table 7 are illustrated graphically in Figure 5 with the cost of tactical air sorties along the horizontal axis and reductions in throughput on the vertical axis. Two efficient cost functions are plotted, one with the number of gunship team sorties variable and the other with the number of gunship team sorties constrained at 65 per week. The optimal points for attaining a reduction in throughput of 436 truckloads are designated on each. If sufficient gunship sorties were available, a cost saving of about \$5 million per week would be

COST REDUCTION POTENTIALS

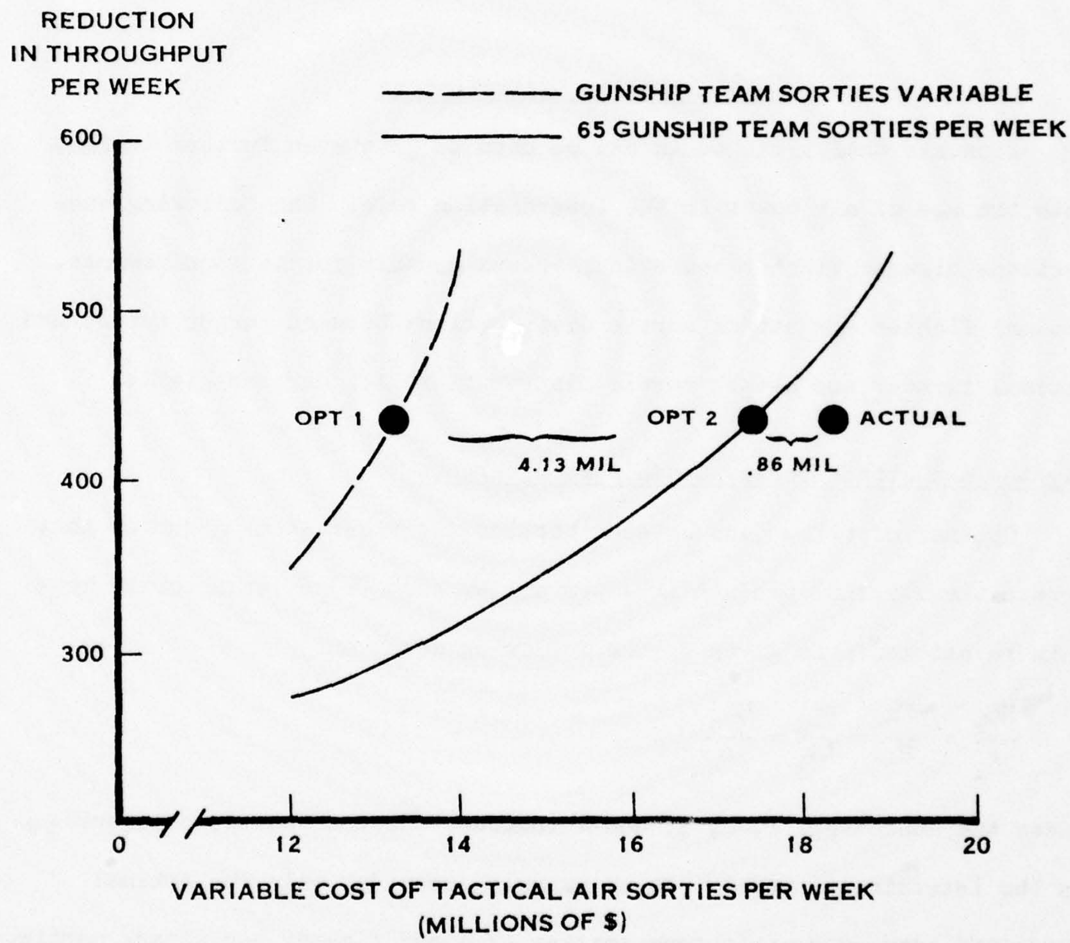


FIGURE 5

possible. With the strike resources available, however, a cost savings of less than \$1 million per week was possible. This is a rather spectacular result. Compared to the \$17.5 million optimal cost, the overrun was only five percent.

Optimal Sortie Distributions

Economic analytical tools can be used to gain even further insight into the use of air power in the interdiction role. The following subsections discuss fighter and attack versus gunship sortie requirements, optimal fighter and attack sortie distributions between target types, and optimal fighter and attack sortie distributions for day and night.

Fighter and Attack Versus Gunship Requirements

Optimal distributions between sorties are predicated on ratios that equate the marginal product (MP) per dollar cost (P) of each sortie type. This relationship is given by the following equation:

$$\frac{MP_1}{P_1} = \frac{MP_2}{P_2} = \frac{MP_3}{P_3} = \frac{MP_4}{P_4}$$

where the subscripts 1, 2, 3, and 4 indicate the four sortie categories in the interdiction model. As an example, consider only the optimal trade-off between gunship team sorties (X_1) and fighter and attack sorties against trucks and storage areas (X_2). Referring to Appendix C, the marginal product of gunship sorties is:

$$MP_1 = \frac{B_1 Y}{X_1},$$

and the marginal product of fighter and attack sorties against trucks and

storage areas is:

$$MP_2 = \frac{B_2Y}{X_2} .$$

Substituting these values in the optimal relationship:

$$\frac{B_1Y}{X_1P_1} = \frac{B_2Y}{X_2P_2}, \text{ or } X_2 = \frac{B_2P_1}{B_1P_2}X_1 .$$

In the interdiction model estimated for this study, the optimal sortie distribution will remain constant as long as there are no changes in the sortie costs. Even if one sortie type is constrained, the optimal distribution between the others remains unchanged.

The above information can be used to calculate the optimal number of fighter and attack sorties that should be employed with gunships in the interdiction role. Table 8 presents the results of this calculation.

TABLE 8

OPTIMAL FIGHTER AND ATTACK SORTIES PER GUNSHIP SORTIE

	Per Gunship Sortie
Trucks and Storage Areas Sorties	2.6
Lines of Communication Sorties	1.5
Close Air Support Sorties	1.3
Total of Above	5.4
Gunship Escorts	3.0
Total	8.4

At the optimum, 8.4 fighter and attack sorties would be required per gunship sortie--5.4 against the specified targets and 3 to escort the gunship. Critics of the interdiction campaign who advocate the sole use of gunship teams on an average output per dollar basis neglect the fact

that on a marginal cost basis, the fighter and attack aircraft are an important part of the interdiction strike force. Even if the cost of fighter and attack sorties were 100 percent greater than that used in this study, 5.7 (2.7 + 3.0) fighter and attack sorties would be employed for each gunship sortie. And for force planning considerations, it should be noted that this evaluation was limited to the tactical air strike force employed in the interdiction role in southern Laos and does not cover fixed support requirements or strike requirements in other areas of Southeast Asia.

Optimal Fighter and Attack Sortie Distribution Between Targets

The results outlined in Table 8 can be used to determine optimal fighter and attack sortie distributions between target types. As an example, for every 100 gunship sorties, we require 300 escort sorties, 260 sorties against trucks and storage areas, 150 sorties against lines of communication, and 130 sorties in the other category. The optimal distribution of sorties based on these figures is given in the top portion of Table 9.

If sufficient gunships are not available to require the percentage of escorts depicted, the excess fighter and attack aircraft should be distributed to the other target categories using the percentages in the table as weighting criteria. This has been accomplished in the lower portion of the table for the campaign average of 65 gunship and 1873 fighter and attack sorties per week. For comparison purposes, the number of sorties actually flown and the percentage breakdown are also given. Basically, the optimum distribution would call for a 12 percent shift of sorties out of the lines of communication category to the trucks and

storage area category. As shown previously in Table 7, approximately 100 sorties per week could be saved with such a shift and the same results obtained.

TABLE 9

OPTIMAL FIGHTER AND ATTACK SORTIE TARGET DISTRIBUTIONS

Target Categories	Optimal Percentages
Gunship Escorts	36
Trucks and Storage Areas	31
Lines of Communication	18
Close Air Support	15
	100

	Optimum with 65 Gunship Sorties		Flown	
	Sorties	Percentages	Sorties	Percentages
Gunship Escorts	195	10	195	10
Trucks and Storage Areas	810	43	579	31
Lines of Communication	465	25	695	37
Close Air Support	403	22	404	22
	1873	100	1873	100

Optimal Fighter and Attack Sortie Distributions by Day and Night

To determine the optimal distribution for day and night, all fighter and attack sorties, with the exception of gunship escorts, were grouped into two categories. These categories, along with that of gunship teams, were used to estimate the parameters of a model similar to that described in Chapter III. The estimated parameters and T ratios for the day and night fighter and attack sorties are given in Table 10. Since the costs are identical, the optimal allocation of sorties is predicated on only the ratio of the Bs. These parameters indicate that the optimal allocation was very close to that actually flown.

TABLE 10

OPTIMAL FIGHTER AND ATTACK SORTIE DISTRIBUTIONS: DAY AND NIGHT

Sortie	B	T Ratio	Optimum	Flown
Day	.75672	5.19	65%	68%
Night	.41112	2.42	35%	32%

Opportunity Costs of Using Air Resources in Other Functions

Often the commander faces a decision whether to employ a given number of air resources in the primary interdiction effort in southern Laos or to support operations in other areas of Southeast Asia. When such a decision is being made, it is important to realize what is being given up or foregone when sorties are reallocated to other than the interdiction function. This is the opportunity, or real, cost of the reallocation. The interdiction model, based on October 1970 through June 1971 experience, enables us to estimate this cost in terms of a reduction in throughput foregone.

Figure 6 provides an illustration of the use of this concept for fighter and attack aircraft, holding gunship escort requirements constant at 195. Based on a monthly total of 10,000 fighter and attack sorties, the figure shows the reduction in throughput foregone as the percentage of the sorties used in other areas of Southeast Asia increases. On the average,the reduction in throughput foregone amounts to about 100 truckloads per week for each 10 percent increase. If the potential benefit of using the sorties elsewhere does not compensate for this cost, the reallocation should not be effected.

OPPORTUNITY COST OF FIGHTER AND ATTACK SORTIES FLOWN IN AREAS OTHER THAN SOUTHERN LAOS

(BASED ON 10,000 FIGHTER AND ATTACK SORTIES PER MONTH)

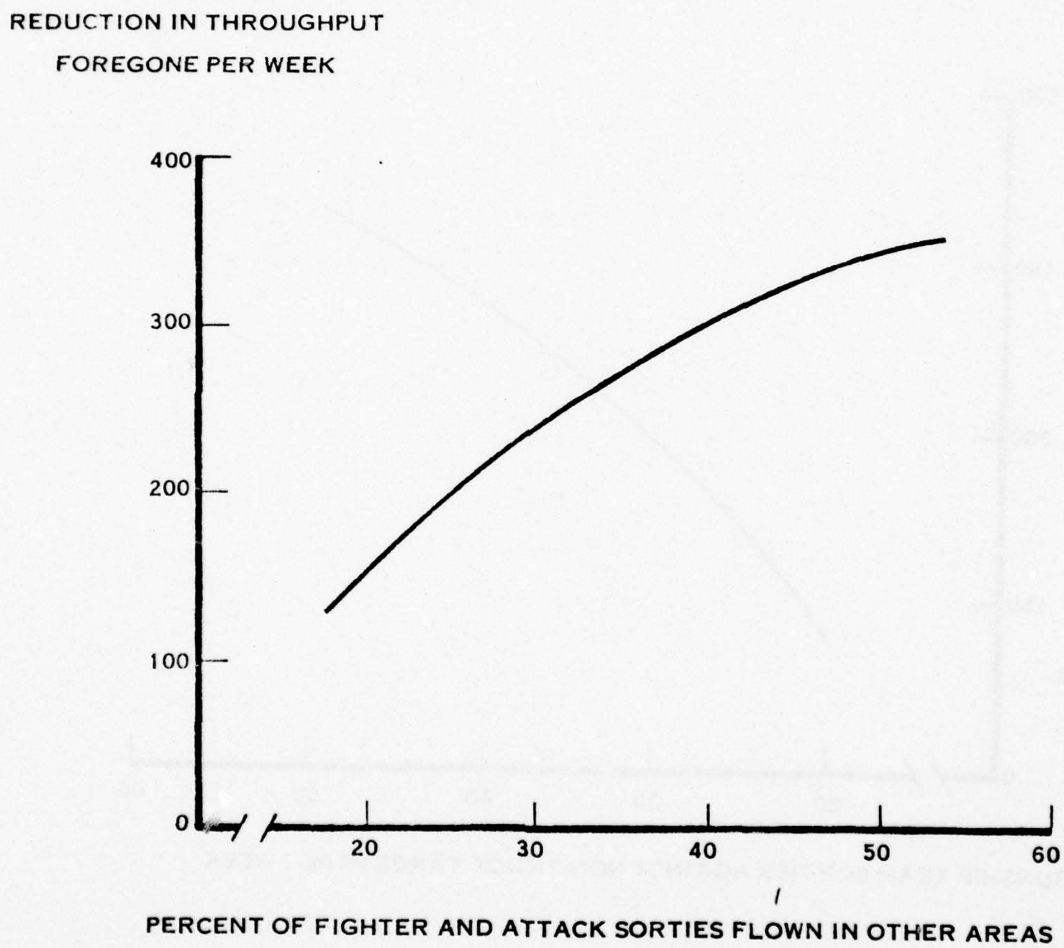


FIGURE 6

OPPORTUNITY COST OF GUNSHIP TEAM SORTIES USED AGAINST TARGETS OTHER THAN TRUCKS IN SOUTHERN LAOS

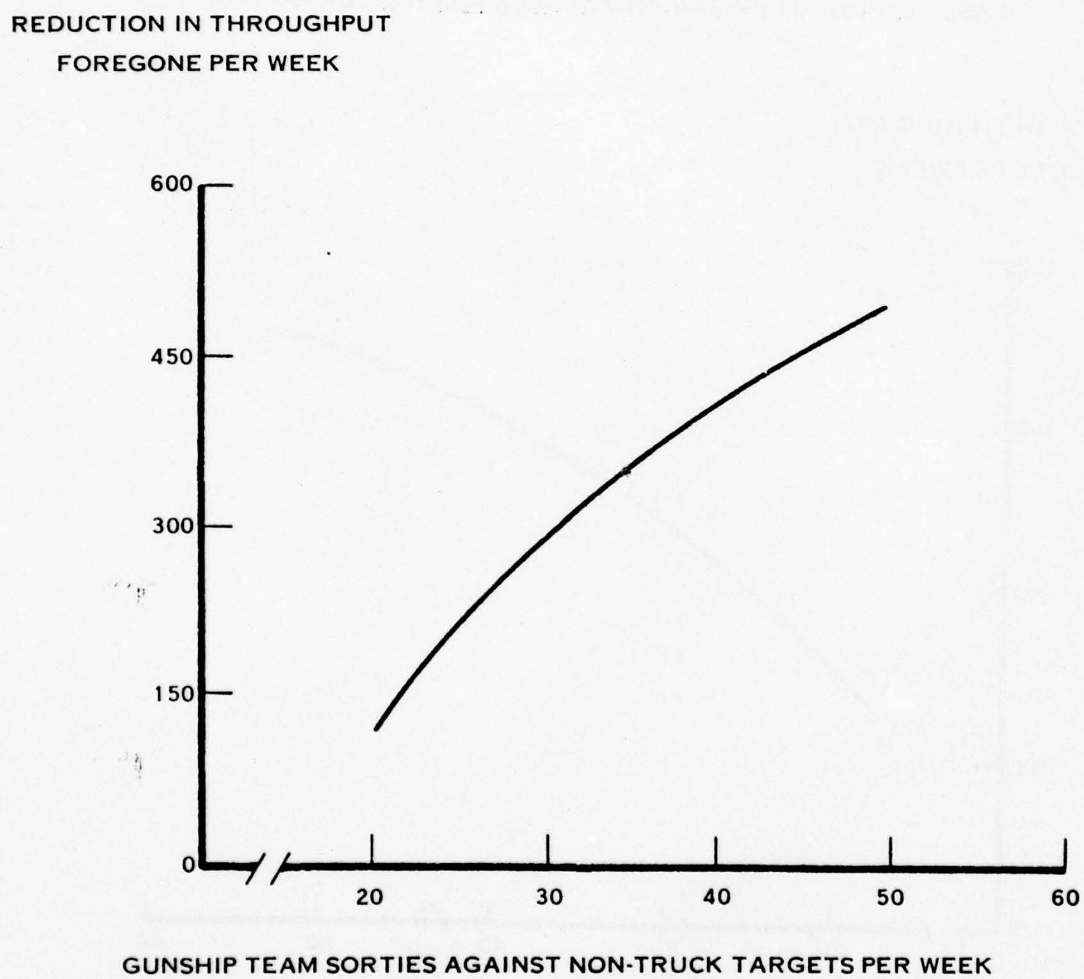


FIGURE 7

Likewise, the real cost of employing gunships in functions other than striking trucks at night can be calculated. Based on a total of 100 gunship sorties, with the fighter and attack sorties held constant at their means, Figure 7 shows the reduction in throughput foregone as more gunships are used to support other operations. The opportunity cost of not using gunships in their primary interdiction role is quite high, and careful consideration should be given to their employment.

Conclusions

The major conclusions of the economic analysis are presented below:

1. The gunship team was the most cost-effective weapons system in the interdiction campaign in Southeast Asia.

2. The estimated optimal allocation called for fewer lines of communication sorties than were flown.

3. Given the strike resources available, the allocation of tactical air sorties was close to optimum. The estimated cost overrun amounted to 5 percent.

4. Including the cost of Arc Light sorties and their support packages--an average of 220 a week at $34,200 per sorties--, the variable cost per week for the strike force was 20 percent above the cost of the previous dry season campaign. Effectiveness, predicated on the reduction of supplies reaching the borders of South Vietnam and Cambodia, however, was up 150 percent.

CHAPTER V

THE REASONS WHY

Effectiveness Against Trucks

Perhaps numerous explanations can be given for the relative success of the aerial interdiction campaign in southern Laos from 10 October 1970 to 30 June 1971. Primary among these, however, must be the effectiveness with which a qualitatively improved strike force was applied against trucks--the most profitable enemy target. Not only was there a vast increase in the number of trucks reported destroyed or damaged (approximately 20,000 during Commando Hunt V versus 10,000 for the previous campaign), but also the number of truck kills was the major factor in reducing throughput.

Take, for example, the model below which relates the objective variable, $IP_{t-6} - TP_t$ to trucks destroyed or damaged and southbound sensor-detected truck movements:

$$Y = AX_1^{B_1}X_2^{B_2}$$

where: Y = The objective variable, $IP_{t-6} - TP_t$

X_1 = Trucks destroyed or damaged per week

X_2 = Southbound sensor-detected truck movements per week.

The estimated parameters and summary statistics of the model, shown in Table 11, are indicative of the highly significant influence of truck kills. The T ratio on the truck kill variable is quite high, and the B value of 1.00848 indicates constant returns as the number of trucks reported destroyed or damaged increased. In addition, this relationship

TABLE 11

ESTIMATED RELATIONSHIP BETWEEN TRUCK KILLS AND THE OBJECTIVE

Variable	B	T Ratio
Trucks Destroyed or Damaged	1.00848	8.81
Southbound Sensor-Detected Movements	-.65819	3.12
Constant = 4.86626 R^2 = .91		

explains 91 percent of the variation in the objective variable.

Holding the influence of southbound sensor-detected truck movements constant at the campaign mean and incorporating this factor in the constant term, the model can be simplified into the following form:

$IP_{t-6} - TP_t = .63625$ (Trucks Destroyed or Damaged).

In words, this means that for each truck destroyed or damaged, approximately .64 less truckloads of throughput were experienced during the time frame defined by the objective variable.

Let us now compare this statistical result with that of another generated during the campaign. Table 12 presents the number of trucks destroyed or damaged by direction for the month of April, the highest truck kill month of the campaign. Forty-four percent of the trucks reported destroyed or demaged were moving south and, presumably, constituted potential throughput. If the parked and direction-unknown vehicles were distributed in proportion to those southbound and northbound, 75 percent of the truck kills would be vehicles carrying potential throughput. If, however, only half the parked and direction-unknown vehicles were loaded with potential throughput, throughput-reducing kills would constitute 65 percent of the total, which is almost identical to

TABLE 12

TRUCK KILLS BY DIRECTION, APRIL 1971

Direction	Destroyed or Damaged	Percentage
Southbound	2542	44
Northbound	858	15
Parked	1017	18
Unknown	1317	23
Total	5734	100

to the .64 reduction for each truck kill obtained by the statistical method described above. This percentage is greater than the average 55 percent southbound bias of sensor-detected truck movements reported during Commando Hunt V, but a majority of truck kills were effected by gunship teams during the earlier evening hours, when the southbound bias was greater than 55 percent.

In summary, we note that there does exist a strong statistical relationship between the objective and trucks destroyed or damaged, and that there is good evidence that a majority of the kills were southbound trucks, which, presumably, constituted potential throughput. Whether this means that the supplies on the trucks were actually destroyed or that the truck kills effected additional resource expenditure and time delay for the enemy, fewer supplies reached the borders of South Vietnam and Cambodia during the time frame covered in the objective variable.

Based on the experience gained in past campaigns, the vital role played by the enemy truck force was recognized early, and a concerted effort was made to position the strike force to destroy this critical element. The degree to which this effort was successful is summarized in the effectiveness formula of Table 13. The value of each term in the

TABLE 13

EFFECTIVENESS FORMULA

$\frac{DD}{SD} = \frac{OB}{SD} \times \frac{ST}{OB} \times \frac{DD}{ST}$	Nov 69-Jun 70	Nov 70-Jun 71
$\frac{DD}{SD} = \frac{\text{Trucks Destroyed or Damaged}}{\text{Sensor-Detected Movement}}$	.06	.12
$\frac{OB}{SD} = \frac{\text{Trucks Observed}}{\text{Sensor-Detected Movement}}$	.24	.24
$\frac{ST}{OB} = \frac{\text{Trucks Struck}}{\text{Trucks Observed}}$	.61	.79
$\frac{DD}{ST} = \frac{\text{Trucks Destroyed or Damaged}}{\text{Trucks Struck}}$	.38	.61

formula provided valuable information and was scrutinized closely. Trucks destroyed or damaged per sensor-detected truck movement gives an overall measure of the truck strike force effectiveness in relation to enemy activity. Trucks observed per sensor-detected movement measures how well the gunship and FAC force was positioned to observe enemy activity. Trucks struck per truck observed measures how well the strike force was allocated to the observers. Finally, trucks destroyed or damaged per truck struck measures the terminal effectiveness of the strike force.

The overall values listed in Table 13 reflect both a qualitative improvement in the strike force and a concerted effort to increase its effectiveness. The Steel Tiger operating area was divided into nine sub-areas (see Appendix A) and equivalent measures by aircraft type were monitored in each sub-area. Any decrease in effectiveness was immediately investigated so that corrective action could be taken. If it was operationally impossible to improve effectiveness in any particular area, the force was reallocated to those locations where its output was highest.

The evidence above indicates a high payoff for the strict attention given the allocation of the force used to strike trucks.

Lam Son 719

The Lam Son 719 ground incursion into Laos was also a primary factor contributing to the success of the interdiction campaign. The combined air and ground forces destroyed large volumes of supplies and forced the enemy to expend valuable resources in his defense. The productivity of the close air support sorties in the interdiction model resulted from their contribution to this joint operation.

Beyond this immediate effect, Lam Son 719 also played an important role in enhancing the effectiveness of other interdiction sorties. The increased logistics requirements forced the enemy to move and concentrate supplies that might otherwise have been delayed or concealed from air strikes. As a result, the productivity of tactical air sorties was considerably increased. This can be shown in the following model which uses weekly data to relate trucks destroyed or damaged to gunship team and fighter and attack sorties against trucks:

$$Y = X_1^{B_1} X_2^{B_2} e^{A + B_3 X_3}$$

where: Y = Trucks destroyed or damaged per week

X_1 = Gunship team sorties per week

X_2 = Fighter and attack sorties against trucks per week

X_3 = Lam Son 719 qualitative variable .

A qualitative, or dummy, variable was used to designate those weeks included in the Lam Son 719 period. The estimated parameters and T ratios given in Table 14 indicate there was a significant increase in

TABLE 14

TRUCK KILL RELATIONSHIPS FOR LAM SON 719

Variable	B	T Ratio
Gunship Team Sorties	1.07779	7.33
Fighter and Attack Sorties Against Trucks	.56220	2.46
Lam Son 719	.40327	2.69
Constant (A) = -1.34348 R^2 = .90		

effectiveness during this period.

The significance of Lam Son 719 can be vividly illustrated in two dimensions by diagramming the relationship between trucks destroyed or damaged and the sorties flown by the gunship teams. This relationship is presented in Figure 8. Even the most effective weapons system showed a decided increase in effectiveness during the Lam Son 719 period. It goes without saying that when the enemy is forced into a main front confrontation and the timing and volume of supplies becomes critical, the strike effectiveness of an interdiction force is at its highest.

In conclusion, the improved effectiveness against enemy trucks and the Lam Son 719 ground incursion are two of many factors that contributed to the success of the aerial interdiction campaign from 10 October 1970 to 30 June 1971. Others could be cited, but these appear to be the primary reasons why the initiative rested more with the U.S. forces than ever before.

EFFECT OF LAM SON 719 ON TRUCKS DESTROYED OR DAMAGED

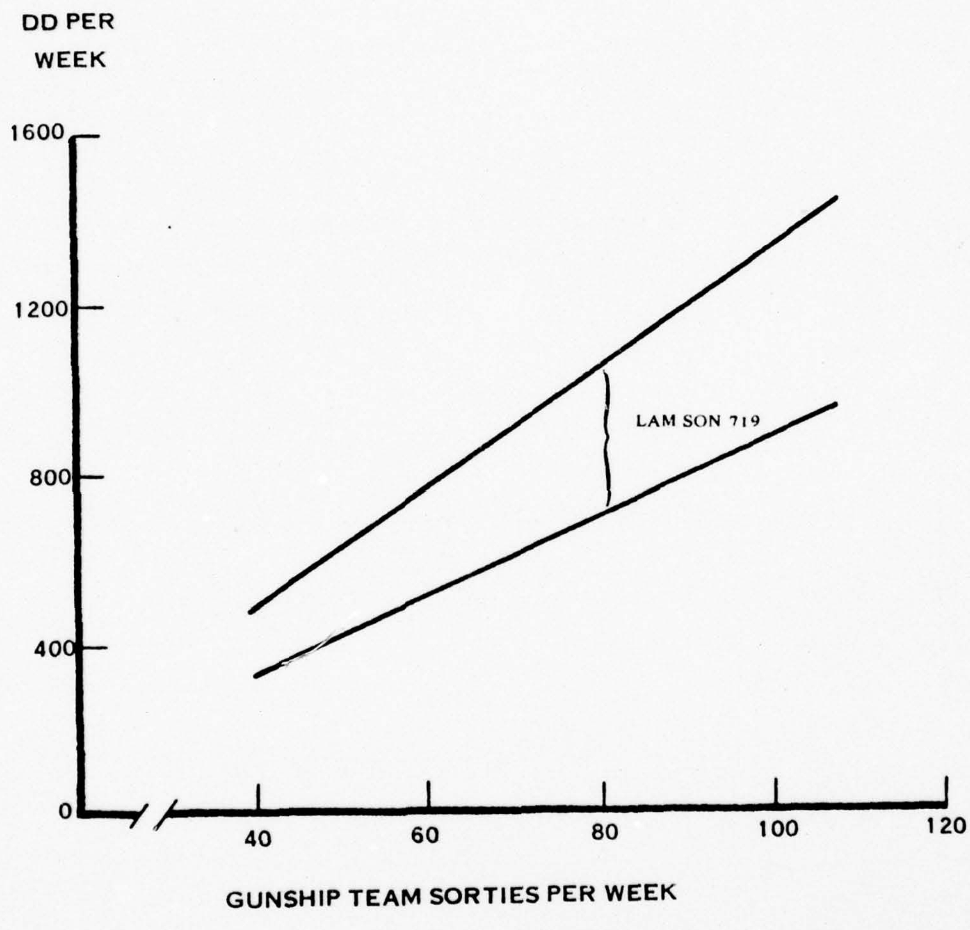


FIGURE 8

APPENDICES

APPENDIX A

AREA ANALYSIS OF ENEMY TRAFFIC MOVEMENT

The lineal nature of the movement of supplies from north to south in southern Laos during Commando Hunt III and V gave rise to an interdependency of traffic movement. In order to investigate this interdependency, the nine analytical sub-areas of southern Laos were consolidated into three larger areas--Entry, Central, and Exit. These areas are depicted in Figure A-1. The traffic flow during the two campaigns proceeded south from the Mu Gia, Ban Karai, and Ban Raving (DMZ area) passes through the entry area into the central route structure. Truckloads of supplies which were not intercepted then moved through the exit area into the Republic of Vietnam during both campaigns and into Cambodia during Commando Hunt V via the exit gates.

It is possible to obtain information about the time pattern of the enemy's traffic movement during the two campaigns using sequential regression equations. Since sensor coverage in each area was not the same, proportional rather than absolute change comparisons were considered more relevant. These changes can be estimated with an exponential function of the following form:

$$Y = AX^B .$$

In this relationship the B indicates the proportional change in Y that could be expected with each unit proportional change in X.

The structure of the total travel time during Commando Hunt III will be discussed first. Table A-1 provides the results of four regressions which related weekly southbound sensor-detected movements (SS) in the

SOUTHERN LAOS INTERDICTION AREAS

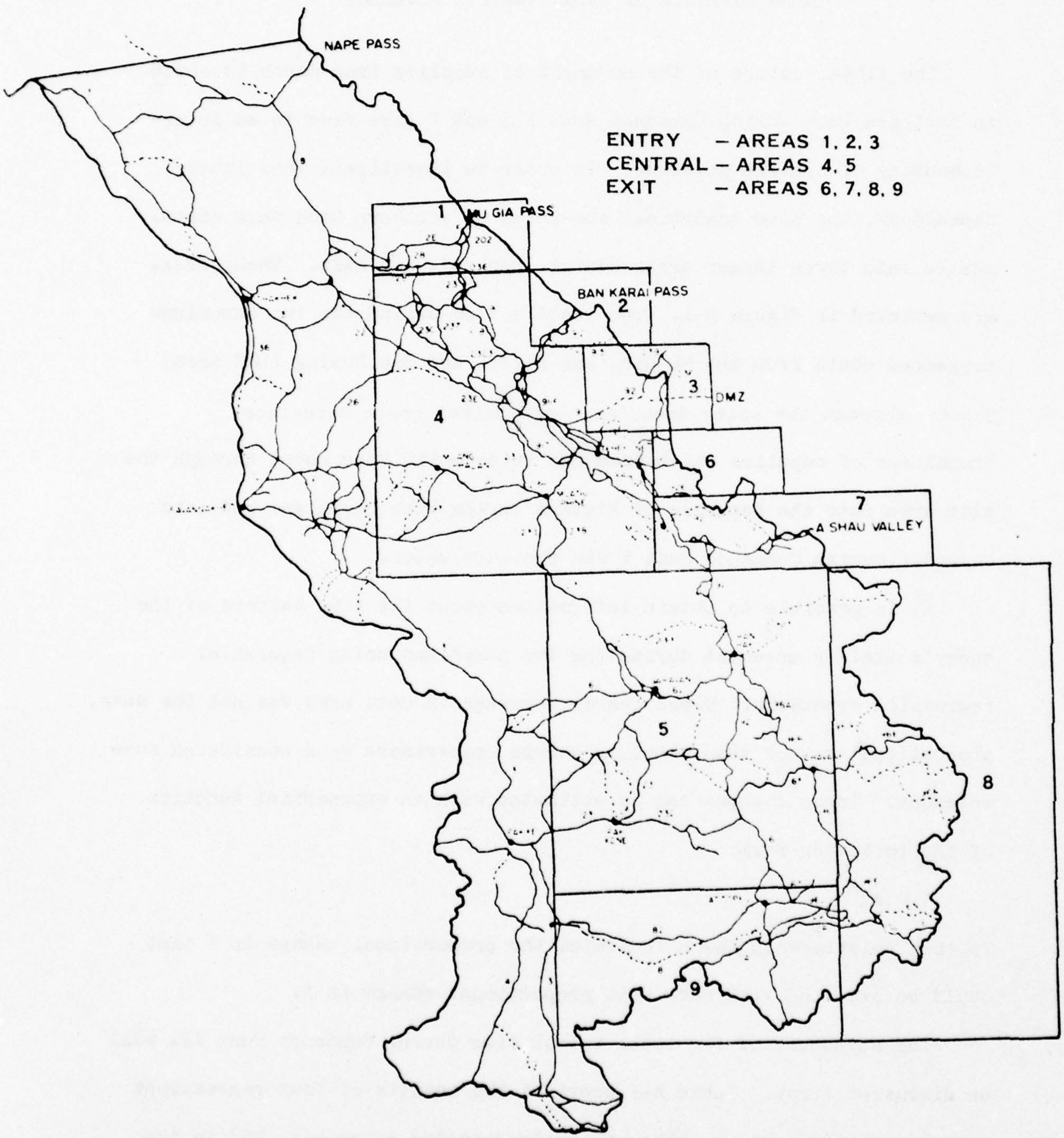


FIGURE A-1

TABLE A-1

COMMANDO HUNT III SOUTHBOUND ACTIVITY RELATIONSHIPS

Area Dependent Variable	Input $TKlds_t$	Entry SS_t	Entry SS_{t-3}	Central SS_t	Exit SS_t	Exit SS_{t-3}
Entry: SS_t	1.60 (10.5)					
Central: SS_t		.329 (1.9)	.418 (1.9)			
Exit: SS_t				1.21 (12.6)		
Throughput: $TKlds_t$					.712 (7.9)	.258 (3.5)

three areas and truckloads (TKlds) of input and throughput in a sequential manner. The number in each explanatory variable column is the estimated value of B. Below each number in parenthesis is the T ratio which measures the confidence in the value of the exponent for a minimum of 29 degrees of freedom.

The first relationship presented is entry area southbound sensor-detected truck movements as a function of input during the same week (t). As expected, no significant lag effect was discovered. The second regression shows that southbound sensor-detected movements in the central area were functionally related to entry area southbound sensor-detected movements both during the current week (t) and the third previous week (t-3). No significant relationship for the weeks t-1 and t-2 was indicated. The three-week delay implies that the supplies were stockpiled either in the entry area or central area.

The next relationship shows exit area southbound sensor-detected

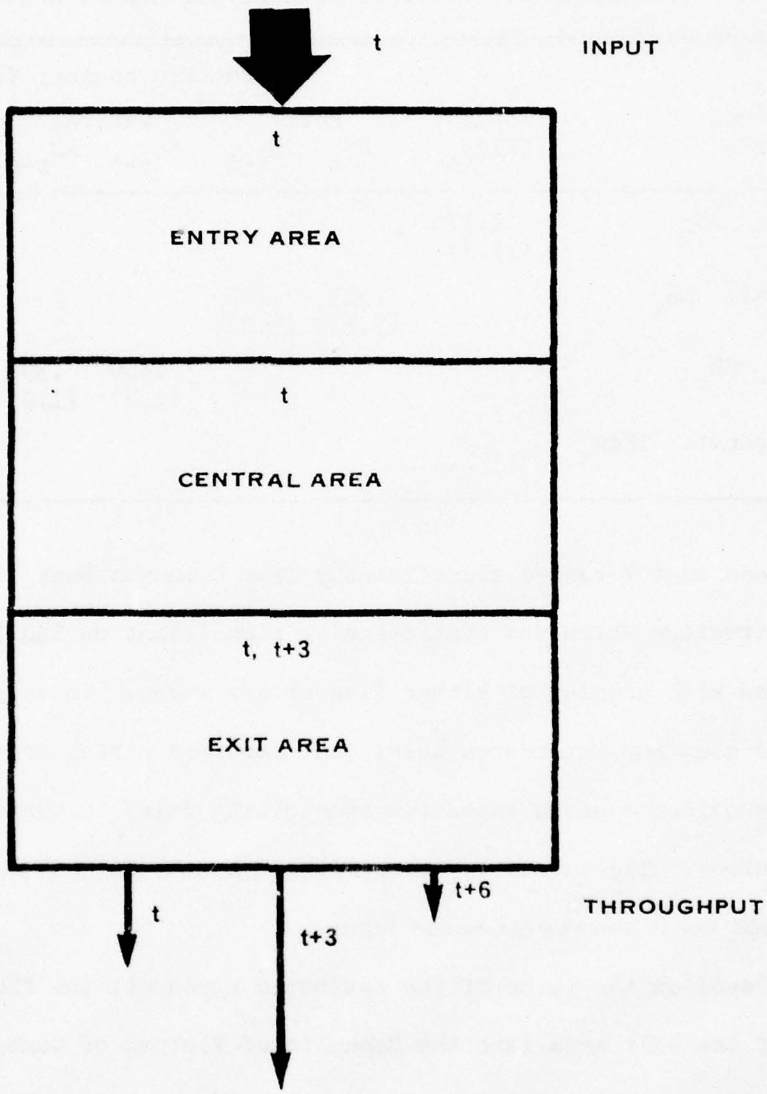
movements as a function of movements in the central area. There was no evidence of a significant lag effect between these two areas. Throughput at the exit gates, however, was a function of both exit area southbound sensor-detected movements during the current week (t) and third previous week (t-3), implying the existence of a second stockpile region in southern Laos.

The various lag effects described above indicate the possibility of several different traffic flows during Commando Hunt III which are diagrammed in Figure A-2. Stockpiling in either the entry and/or central or exit areas resulted in a three-week flow through the system. The four regressions also indicate the possibility of supplies moving through the system during the same week if there were no stockpiling, or in six weeks if the supplies were stockpiled twice. The value of the estimated exponents, however, indicate that the predominant travel time during the campaign was three weeks. This corresponds with the high correlation between throughput during week t and input during week t-3 described in Chapter I.

Table A-2 provides the results of four regressions for the Commando Hunt V time frame. Again the T ratios are based on a minimum of 29 degrees of freedom.

There was again no significant lag effect between input and entry area southbound sensor-detected truck movements. Between the entry and central areas during Commando Hunt V, the travel time spanned two weeks--movement between areas either during the same week or during consecutive weeks.

The traffic pattern between the exit and central areas during



COMMANDO HUNT III TRAFFIC FLOWS

FIGURE A-2

TABLE A-2

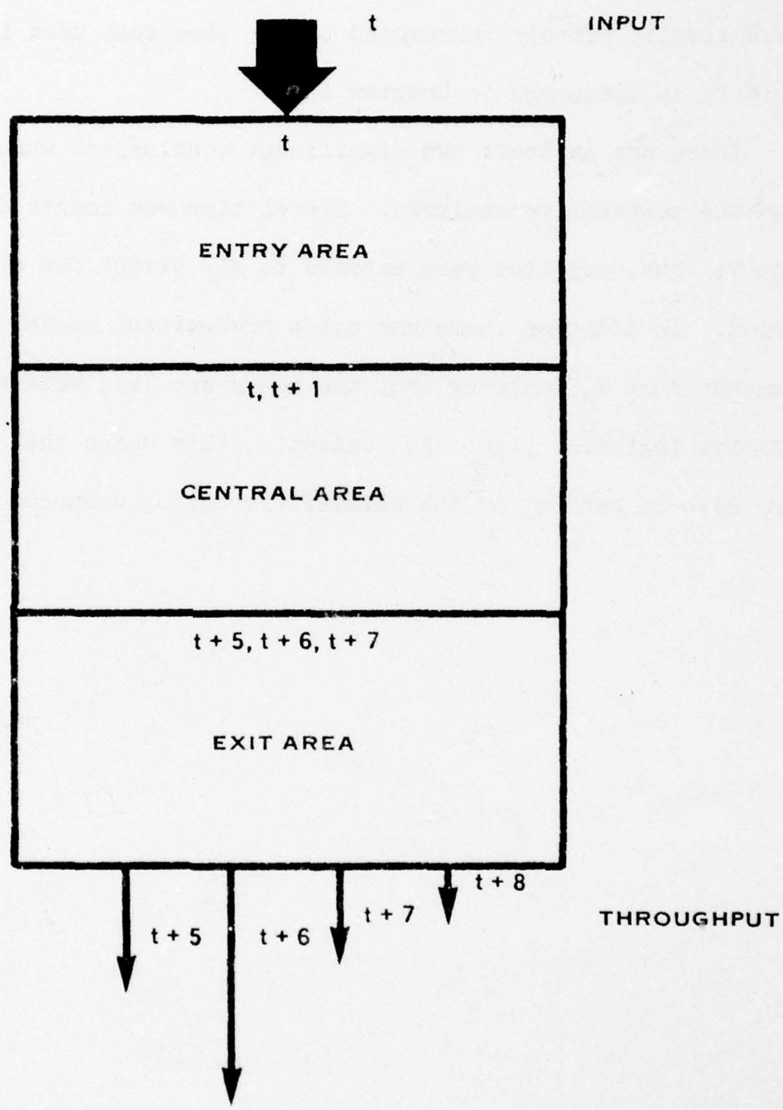
COMMANDO HUNT V SOUTHBOUND ACTIVITY RELATIONSHIPS

Area Dependent Variable	Input $TKlds_t$	Entry SS_t	Entry SS_{t-1}	Central SS_{t-5}	Central SS_{t-6}	Exit SS_t	Exit SS_{t-1}
Entry: SS_t	1.17 (17.1)						
Central: SS_t		.503 (7.3)	.222 (3.0)				
Exit: SS_t				.409 (1.8)	.396 (1.9)		
Throughput: $TKds_t$						.569 (9.8)	.176 (3.2)

Commando Hunt V varied significantly from Commando Hunt III. The only lag structure which was statistically significant during Commando Hunt V was one with a delay of either five or six weeks. These lags were larger than any inter-area delay that occurred during Commando Hunt III and is evidence of an extensive stockpiling delay in the central and/or exit areas. The extensive stockpiling justifies the emphasis against storage areas during Commando Hunt V.

Based on the value of the estimated exponent, the flow of supplies out of the exit area into the Republic of Vietnam or Cambodia predominantly occurred during the same week, although some of the supplies took as many as two weeks to move out of the exit area.

The possible traffic flows that may be inferred from the regression analysis are shown in Figure A-3. The most prevalent travel times for supplies in southern Laos were five through seven weeks. Some supplies appear to have taken as many as eight weeks to move through the logistic



COMMANDO HUNT V TRAFFIC FLOWS

FIGURE A—3

system, although this amount of travel time was not nearly as prevalent. These results closely correspond to the time span used in the objective variable as discussed in Chapter I.

There are at least two significant conclusions which may be drawn from the comparative analysis. Travel time was longer during Commando Hunt V; thus, supplies were exposed to air attack for a longer time period. In addition there was not a predominant travel time during Commando Hunt V, implying that the enemy was less able to execute a definite logistics plan. Equivalently, this means that U.S. air forces were more in control of the battlefield during Commando Hunt V.

APPENDIX B

ESTIMATION OF THE INTERDICTION MODEL

When the technique of multiple regression is used, certain assumptions are made about the character of the error term, u, in the regression model:

$$Y = A + BX + u \ .$$

Specifically, we assume that the error term is independently distributed with a mean equal to zero. If it is not, the estimated parameters will be biased and inefficient. In addition, for efficiency though not for bias, the variance of the error term should be constant from one observation to another. An investigation of the statistical properties of a model therefore centers on the evaluation of the error terms.

The first question that normally arises is how the accuracy of the data affects the assumptions listed above. Inaccurate values of the explanatory variable, X, would be detrimental because a dependence would then exist between the error term and the explanatory variable. Consequently, the error term would not be distributed independently of X and the result would be a biased estimate of B. In this study, however, the primary explanatory variables were numbers of sorties flown and these data are considered reasonably accurate.

Some may not put the same confidence in the dependent variable, Y, or $IP_{t-6} - TP_t$, which was used in the model. Input and throughput are

estimates based on the best information available to intelligence analysts. Although a conscientious effort was made to calculate these numbers as accurately as possible, they are still estimates and may be subject to some error. Errors in the dependent variable, however, are not as critical as those in the explanatory variables.

In the regression model above, the parameter, B, is the marginal product of X and provides an estimate of the change that would take place in Y for a unit change in X. As such, the value of B is not predicated on the absolute value of Y. A persistent bias in Y would be reflected in the constant term, A, which is not of particular importance in a marginal analysis. Random inaccuracies in Y are picked up in the error term, u, and as long as u is distributed independently of X, with a mean of zero, the estimate of B will be unbiased. In summary, then, there is no definite evidence that the estimated exponents of the interdiction model are biased as a result of errors in the data.

The other statistical properties of the model can best be explained by comparing its properties with those of several other possible specifications. The first is a basic linear regression model of the following form:

$$Y = A + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + u.$$

The parameters, A and Bs, of this model are linear functions of the dependent variable, Y, and can be estimated directly. This model is designated Model A in the remainder of the appendix.

The second model is a multiplicate or exponential model, similar to that used in the study. It takes the following form:

$$Y = AX_1^{B_1} X_2^{B_2} X_3^{B_3} X_4^{B_4} X_5^{B_5} u.$$

The parameters of this model are not linear functions of Y, so a natural logarithmic (Ln) transformation is required. The model actually estimated is given below:

$$\text{LnY} = \text{LnA} + B_1\text{LnX}_1 + B_2\text{LnX}_2 + B_3\text{LnX}_3 + B_4\text{LnX}_4 + B_5\text{LnX}_5 + \text{Lnu}.$$

In this form, the parameters become linear functions of the dependent variable, LnY and least squares estimation is possible. Certain methodological changes, however, are required. First, the assumptions on the error term, u, outlined above, apply now to the transformed error term, Lnu. Second, the antilog of the constant term, LnA, in the estimated form must be calculated to obtain the coefficient, A, in the original expression. The Bs, however, are estimated directly and require no further transformation. This model is designated Model B in the subsequent comparisons.

Model C, the interdiction model utilized in this study, is a special case of Model B above, in which the constant, LnA, is assumed to equal zero (i.e. A=1) and the data is normalized to account for the large change in enemy activity levels that took place during the campaign. The parameters of this model were therefore estimated after deflating the data by the natural logarithm of southbound sensor-detected truck movements, LnX_5. Dividing the above equation by LnX_5 resulted in the following form for estimation:

$$\frac{\text{LnY}}{\text{LnX}_5} = B_1 \frac{\text{LnX}_1}{\text{LnX}_5} = B_2 \frac{\text{LnX}_2}{\text{LnX}_5} + B_3 \frac{\text{LnX}_3}{\text{LnX}_5} + B_4 \frac{\text{LnX}_4}{\text{LnX}_5} + B_5 + \frac{\text{Lnu}}{\text{LnX}_5}.$$

The Bs are again estimated directly and can be used in the original exponential form. The constant term in the model actually estimated, B_5, is the exponent of the southbound sensor-detected truck movements variable. If LnA is not equal to zero, the constant term estimated in the above model will be the sum of: $B_5 + \text{LnA}\ (1/\text{LnX}_5)$, which, of course, is a biased estimated of B_5. As a further check on the validity of the assumption that LnA = 0, an extended version of Model C with the term, $1/\text{LnX}_5$, was estimated and included as Model C'.

The estimated parameters and summary statistics for the four models described above are presented in Table B-1. The numbers in parentheses are T ratios or tests for each of the estimated parameters and are based on the null hypothesis that the value of the parameter is zero. The parameters were estimated using 32 data points or weekly observations.

Attention is directed first to the parameters and summary statistics for Model A, the linear model. Only the gunship team exponent is statistically significant at the 95 percent confidence level. In all other cases, we cannot reject the null hypothesis that B = 0, or that there is no relationship between the various sortie sets and the objective variable. What's more, the estimated parameters of lines of communication and direct air support sorties are negative and that of southbound sensor-detected movements positive, which _a priori_ does not appear reasonable.

The large value of the constant term, 409, is close to the campaign average of the objective variable, 436. This indicates the model is badly misspecified because if all variables that influence the objective

Table B-1. Comparative Model Parameters

Variables and Summary Statistics	Model A B (T ratio)	Model B B (T ratio)	Model C B (T ratio)	Model C' B (T ratio)
Gunship Team Sorties	4.33486 (2.05)	1.35251 (4.02)	1.30699 (5.32)	1.32006 (4.03)
Trucks and Storage Areas Sorties	.02932 (.16)	.51009 (2.11)	.57201 (2.45)	.57514 (2.36)
Lines of Communication Sorties	-.38778 (1.53)	.41316 (.57)	.33317 (2.01)	.37740 (.51)
Direct Air Support Sorties	-.21536 (.99)	.31341 (.82)	.27748 (2.26)	.30045 (.77)
Southbound Movements	.02536 (.43)	-.85102 (2.05)	- -	- -
Reciprocal of Southbound Movements	-	-	-	-.32401 (.06)
Constant Term	409.30182 (1.53)	-.47857 (.09)	-.84535 (3.69)	-.86663 (2.08)
R^2	.875	.933	.857	.857
Durbin-Watson	1.08	1.20	1.22	1.23

variable are included in their proper from, the constant would theoretically be zero. This is substantiated by the low value, 1.08, of the Durbin-Watson statistic. Based on the number of data points and parameters estimated, a Durbin-Watson value this low implies positive autocorrelation of the error terms. This means that the basic assumption that the error terms are independently distributed has been violated. Incorrect specification of the form of the relationship between the variables in the model can result in part of the influence of the explanatory variables being carried by the error terms. Then, if there is any serial correlation in the explanatory variables, we shall also have serial or autocorrelation in the composite error term. Autocorrelation does not imply that the estimated parameters are biased, but they are definitely not the most efficient estimates obtainable.

From a point of realism, the linear model also has certain shortcomings. It implies that the marginal contribution of the input variables is constant throughout their operational range. Normally, we might expect diminishing returns as the value of a variable is increased with the others held constant. Therefore, a nonlinear specification would seem more proper. In addition, the linear specification implies that the contributions of the input variables are independent and additive. In other words, the marginal product of one type sortie is completely independent of the number of other type sorties being flown. This again does not appear to be a realistic assumption.

A model specification that incorporates varying returns and an interaction between inputs, yet is simple to understand and estimate is the exponential form used in Model B. That this specification provides better results is apparent in a comparison of the estimated parameters and summary statistics of Models A and B in Table B-1. Although the T ratios on lines of communication and direct air support sorties are low, all exponents, a priori, now have reasonable signs. The value of the R^2 statistic is higher and the Durbin-Watson statistic has increased in value to a point in the inconclusive range in which one cannot assert that the error terms are autocorrelated. There can be no question that the Model B specification is a decided improvement over that of Model A.

Model C, which is a variant of Model B, was specified to further improve on the estimated parameters used in this study. An evaluation of the Model B statistical properties indicated that the efficiency of the estimated parameters could be improved if the data were deflated or normalized by a size variable. This technique is often used, for example, in estimating investment functions where the sizes of the firms in the sample vary considerably. Deflating the data by a size measure normalizes this influence so that other pertinent cause and effect relationships may be investigated. The magnitude of the enemy's effort to push supplies to the borders of South Vietnam and Cambodia varied considerably over the campaign and this effort was best reflected by the number of south-bound sensor-detected truck movements. Therefore, this variable was selected for use in deflating the data so that the relationship between sortie inputs and the objective variable could be more appropriately analyzed.

Deflation results in increased efficiency of the estimated parameters if the explanatory variable data, when plotted against the size measure, fan out systematically in a linear fashion from the origin (5:34-44). Fanning was especially apparent in plots of the natural logarithm values for lines of communication and direct air support sorties and the improvement in efficiency resulting from deflation is evident in the higher T ratios for Model C in Table B-1.

A related problem in econometrics is heteroscedasticity of the error terms. For estimating efficiency not only should the error terms be independently distributed, but also they should have a constant variance. Although heteroscedasticity of error terms did not appear as a serious problem in Model B, some improvement in the scatter pattern of error terms was noted in the Model C plots. Consequently, an added benefit of the deflation was the improved efficiency that resulted from a more homoscedastic error term variance for Model C.

One potential problem with deflation is the creation of spurious correlation between variables, especially if the deflating variable is very large relative to the data being deflated. This would lead one to

believe there is a higher correlation between the dependent and explanatory variables than actually exists. The higher correlations could also complicate the problem of estimating the separate influences of the explanatory variables, a phenomenon associated with multicollinearity.

A comparison of the R^2 statistics, .93 for Model B and .86 for Model C, indicates that deflation resulted in lower, not higher, correlations between the dependent and explanatory variables. In addition, deflation reduced the correlations among the explanatory variables, thereby alleviating an initial problem with multicollinearity. This is evident in the value of the determinant of the correlation matrix which is a good check for multicollinearity. The value of the determinant increased from .0004 in Model B to .1044 in Model C. The problem of spurious correlation, which often accompanies deflation, therefore did not materialize. Deflation by the natural logarithmic value, which is much lower than the actual value, did not generate the potentially harmful effects discussed above. On the contrary, the efficiency of the estimated parameters was greatly improved.

A comparison of the estimated parameters and summary statistics for Models B and C in Table B-1 gives evidence that the specification of Model C is superior to that of Model B. The T ratios on all estimated parameters are higher for Model C, indicating that these estimates are more efficient than those of Model B. It is also interesting to note that the values of the parameters for each sortie set are quite similar to those of Model B, indicating that deflation did not distort the estimated values. Even the exponent of the southbound sensor-detected truck movements variable, which was the constant term in the Model C estimation, is quite similar to the exponent actually estimated in Model B.

There are yet further indications that support the assumption that the coefficient, A, is equal to one, and consequently LnA equals zero, in the specification of Model C. Note, for instance, that the T ratio on the constant term (LnA) of Model B is a highly insignificant .09, implying that the constant is indeed zero. In addition, in Model C', the extended version of Model C, the T ratio on the coefficient of the reciprocal of southbound sensor-detected truck movements ($1/LnX_5$) is an insignificant .06. If the estimated constant of Model C were truly $B_5 + LnA(1/LnX_5)$ instead of B_5, we might expect the T ratio to be much higher. In conclusion then, all evidence indicates that LnA is zero and that the Model C specification is superior to that of Model B. The close similarity of the estimated values across all exponential specifications gives further assurance that the parameters are relatively stable and that deflation had no deleterious effects.

The R^2 statistic is lower for Model C, but as explained above, the deflation procedure decreased the correlation coefficients between variables so this was expected. Actually, the R^2 statistic is only of secondary importance for the type of model estimated and the use to which the model was put in this study. R^2 is important in a predictive model, but in a policy response model we are primarily interested in the estimated parameters and the confidence that can be put in them.

Optimal allocations are predicated on the estimated B values, and the T ratios give the level of confidence that can be placed on these estimates. Nevertheless, 86 percent of the variance of the objective variable has been explained by the model and this is a high value by most standards.

The difference in the values of the Durbin-Watson statistics for the two models is insignificant. As expected, deflation minimized the detrimental effect of heteroscedasticity but made an insignificant contribution in reducing autocorrelation. The value of 1.22 lies in the inconclusive range between 1.09, below which there is good evidence that autocorrelation is a detrimental factor, and 1.63, above which one can be relatively confident that it is not. Certainly a higher Durbin-Watson value would be desirable, but it is doubtful that additional refinements would significantly increase the value. Some autocorrelation is inherent in time series data, particularly data that has been averaged over time to reflect a lagged influence. Probably the best that can be expected is a value in the inconclusive range where there is no definite evidence that autocorrelation exists.

APPENDIX C

MATHEMATICS OF CONSTRAINED OPTIMIZATION

Cost Minimization Subject to Constraints

Problem (Optimum 1)

Minimize: The cost of sorties flown

Subject to: IP - TP, designated by Y, is a given value.

Mathematical Formulation

Minimize: $P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4$

Subject to: $AX_1^{B_1}X_2^{B_2}X_3^{B_3}X_4^{B_4} = Y = C$ (constant)

where: $Pi(i=1,2,3,4)$ = Cost of type i sortie

$Xi(i=1,2,3,4)$ = Number of type i sorties

$AX_1^{B_1}X_2^{B_2}X_3^{B_3}X_4^{B_4}$ = The interdiction model

C = Given value of IP - TP.

Set up the Lagrange function with the IP - TP constraint:

$$(1)\quad L = P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 - M_1(AX_1^{B_1}X_2^{B_2}X_3^{B_3}X_4^{B_4} - C).$$

Minimize the function by taking partial derivatives with respect to each variable and set equal to zero: (M_1, the Lagrange multiplier, is also a variable.)

$$(2)\quad \frac{\partial L}{\partial X_1} = P_1 - M_1\left(\frac{B_1Y}{X_1}\right) = 0$$

$$(3)\quad \frac{\partial L}{\partial X_2} = P_2 - M_1\left(\frac{B_2Y}{X_2}\right) = 0$$

$$(4)\quad \frac{\partial L}{\partial X_3} = P_3 - M_1\left(\frac{B_3Y}{X_3}\right) = 0$$

$$(5)\quad \frac{\partial L}{\partial X_4} = P - M_1\left(\frac{B_4 Y}{X_4}\right) = 0$$

$$(6)\quad \frac{\partial L}{\partial M_1} = - AX_1^{B_1}X_2^{B_2}X_3^{B_3}X_4^{B_4} + C = 0.$$

Divide (2) by (3), (4), and (5):

$$(7)\quad \frac{B_1X_2}{B_2X_1} = \frac{P_1}{P_2} \text{ or, } X_2 = \frac{B_2P_1}{B_1P_2} X_1$$

$$(8)\quad \frac{B_1X_3}{B_3X_1} = \frac{P_1}{P_3} \text{ or, } X_3 = \frac{B_3P_1}{B_1P_2} X_1$$

$$(9)\quad \frac{B_1X_4}{B_4X_1} = \frac{P_1}{P_2} \text{ or, } X_4 = \frac{B_4P_1}{B_1P_4} X_1.$$

Substitute (7), (8) and (9) into (6):

$$(10)\quad AX_1^{B_1}\left(\frac{B_2P_1}{B_1P_2} X_1\right)^{B_2}\left(\frac{B_3P_1}{B_1P_3}\right)^{B_3}\left(\frac{B_4P_1}{B_1P_4}\right)^{B_4} = C.$$

Gather terms and solve for X_1:

$$(11)\quad X_1 = \left[\left(\frac{C}{A}\right)\left(\frac{B_1P_2}{B_2P_1}\right)^{B_2}\left(\frac{B_1P_3}{B_3P_1}\right)^{B_3}\left(\frac{B_1P_4}{B_4P_1}\right)^{B_4}\right]^{\frac{1}{B_1+B_2+B_3+B_4}}.$$

Use X_1 to solve for other variables in the previous equations:

$$(7)\quad X_2 = \frac{B_2P_1}{B_1P_2} X_1 ,\ \frac{B_2P_1}{B_1P_2} = \text{Optimal trade-off between } X_1 \text{ and } X_2$$

$$(8)\quad X_3 = \frac{B_3P_1}{B_1P_3} X_1 ,\ \frac{B_3P_1}{B_1P_3} = \text{Optimal trade-off between } X_1 \text{ and } X_3$$

$$(9)\quad X_4 = \frac{B_4P_1}{B_1P_4} X_1 ,\ \frac{B_4P_1}{B_1P_4} = \text{Optimal trade-off between } X_1 \text{ and } X_4$$

$$(2)\quad M = \frac{P_1X_1}{B_1C} = \text{Marginal cost of a one truckload reduction in TP at the optimum.}$$

NOTE: The term $\left(\frac{B_iY}{X_i}\right)$ in equations (2), (3), (4), and (5) is the marginal product of sortie X_i. In equations (7), (8), and (9), the ratios

of the marginal products were set equal to the ratios of costs to obtain the optimal trade-offs.

Problem (Optimum 2)

Minimize: The cost of sorties flown

Subject to: (1) Y is a given value

(2) Gunship team sorties = $65(X_1 = S_1)$.

Set up the Lagrange function:

$$(1)\quad L = P_1X_1 + P_2X_2 + P_3X_3 + P_4X_4 - M_1(AX_1^{B_1}X_2^{B_2}X_3^{B_3}X_4^{B_4} - C) - M_2(X_1 - S_1)\ .$$

Take partial derivatives and set equal to zero:

$$(2)\quad \frac{\partial L}{\partial X_1} = P_1 - M_1\left(\frac{B_1 Y}{X_1}\right) - M_2 = 0$$

$$(3)\quad \frac{\partial L}{\partial X_2} = P_2 - M_1\left(\frac{B_2 Y}{X_2}\right) = 0$$

$$(4)\quad \frac{\partial L}{\partial X_3} = P_3 - M_1\left(\frac{B_3 Y}{X_3}\right) = 0$$

$$(5)\quad \frac{\partial L}{\partial X_4} = P_4 - M_1\left(\frac{B_4 Y}{X_4}\right) = 0$$

$$(6)\quad \frac{\partial L}{\partial M_1} = -AX_1^{B_1}X_2^{B_2}X_3^{B_3}X_4^{B_4} + C = 0$$

$$(7)\quad \frac{\partial L}{\partial M_2} = -X_1 + S_1 = 0\ .$$

Divide (3) by (4) and (5):

$$(8)\quad \frac{B_2X_3}{B_3X_2} = \frac{P_2}{P_3}\ ,\ X_3 = \frac{B_3P_2}{B_2P_3}X_2$$

$$(9)\quad \frac{B_2X_4}{B_4X_2} = \frac{P_2}{P_4}\ ,\ X_4 = \frac{B_4P_2}{B_2P_4}X_2\ .$$

Substitute (7), (8), and (9) into (6):

$$(10)\quad A(S_1)^{B_1} X_2^{B_2} \left(\frac{B_3P_2}{B_2P_3} X_2\right)^{B_3} \left(\frac{B_4P_2}{B_2P_4} X_2\right)^{B_4} = C.$$

Gather terms and solve for X_2:

$$(11)\quad X_2 = \left[\left(\frac{C}{A}\right)\left(\frac{1}{S_1}\right)^{B_1}\left(\frac{B_2P_3}{B_3P_2}\right)^{B_3}\left(\frac{B_2P_4}{B_4P_2}\right)^{B_4}\right]^{\frac{1}{B_2+B_3+B_4}}.$$

Use X_2 to solve for the other variables:

$$(8)\quad X_3 = \frac{B_3P_2}{B_2P_3} X_2 \,,\ \frac{B_2P_2}{P_2P_3} = \text{Optimal trade-off between } X_3 \text{ and } X_2$$

$$(9)\quad X_4 = \frac{B_4P_2}{B_2P_4} X_2 \,,\ \frac{B_4P_2}{B_2P_4} = \text{Optimal trade-off between } X_4 \text{ and } X_2$$

(2) $M_1 = \frac{P_2X_2}{B_2C}$ = Marginal cost of a truckload reduction in throughput at the optimum

(5) $M_2 = P_1 - M_1\left(\frac{B_1C}{X_1}\right)$ = Decrease in cost if one additional X_1 sortie were available, i.e., the marginal value of an X_1 sortie.

Output Maximization Subject to Resource Constraints

Problem

Maximize: IP - TP, designated Y

Subject to: The number of sorties available .

Mathematical Formulation

Maximize: $AX_1^{B_1}X_2^{B_2}X_3^{B_3}X_4^{B_4} = Y$

Subject to: (1) $X_1 = S_1$ (Gunship team sorties)

(2) $X_2 + X_3 + X_4 = S_2$ (Fighter and attack sorties).

Set up the Lagrange function:

$$(1)\quad L = AX_1^{B_1}X_2^{B_2}X_3^{B_3}X_4^{B_4} - M_1(X_1-S_1) - M_2(X_2+X_3+X_4-S_2).$$

Maximize the function by taking partial derivatives and set equal to zero:

(2) $\frac{\partial L}{\partial X_1} = \frac{B_1 Y}{X_1} - M_1 = 0$

(3) $\frac{\partial L}{\partial X_2} = \frac{B_2 Y}{X_2} - M_2 = 0$

(4) $\frac{\partial L}{\partial X_3} = \frac{B_3 Y}{X_3} - M_2 = 0$

(5) $\frac{\partial L}{\partial X_4} = \frac{B_4 Y}{X_4} - M_2 = 0$

(6) $\frac{\partial L}{\partial M_1} = - X_1 + S_1 = 0$

(7) $\frac{\partial L}{\partial M_2} = - X_2 - X_3 - X_4 + S_2 = 0$.

Divide (3) by (4) and (5):

(8) $\frac{B_2 X_3}{B_3 X_2} = 1$ or, $X_3 = \frac{B_3}{B_2} X_2$

(9) $\frac{B_2 X_4}{B_4 X_2} = 1$ or, $X_4 = \frac{B_4}{B_2} X_2$.

Substitute (8) and (9) into (7) and solve for X_2

(10) $X_2 = S_2 \left(\frac{B_2}{B_2 + B_3 + B_4}\right)$.

Use X_2 to solve for X_3 and X_4 in the previous equations:

(8) $X_3 = \frac{B_3}{B_2} X_2$

(9) $X_4 = \frac{B_4}{B_2} X_2$.

Substitute values of $X_1 = S_1$, X_2, X_3, and X_4 into original production function and calculate Q to obtain the maximum reduction in throughput:

(11) $A X_1^{B_1} X_2^{B_2} X_3^{B_3} X_4^{B_4} = Y$.

NOTE: The Lagrange multipliers, M_1 and M_2, in this formulation are the marginal products of the sorties at the optimal point. Their values can be obtained by solving equations (2) and (3). These values indicate how much additional Y could be obtained if one additional gunship team sortie or fighter and attack sortie, respectively, were available.

APPENDIX D

GRAPHICAL PRESENTATION OF CONSTRAINED OPTIMIZATION

The problem-solving methodology used in Chapter IV can be illustrated in a two-dimensional diagram if we group all fighter and attack aircraft into one category and assume they have been efficiently allocated, according to the estimated interdiction model, to trucks and storage areas, lines of communication, and close air support. We then have only two inputs to consider, the combined fighter and attack sorties and the gunship team sorties, and we seek the least-cost combination of these two inputs to attain the given output, or a reduction in throughput of 436 truckloads per week. This is illustrated in the isoquant-isocost diagram of Figure D-1. The diagram is for illustrative purposes and should not be taken as an exact reproduction of the cost and output functions. It has also been scaled to better depict the various constrained solutions.

The least-cost combination of sorties is depicted by point A on the diagram where the given "436" isoquant is tangent to the lowest cost line of $13.3 million. This is the Optimum 1 solution of Chapter IV. This solution, however, called for 134 gunship team sorties, more than were available to strike trucks during the campaign. We must therefore move down along the isoquant, or equal-output, line away from the least-cost solution to point B which is constrained at 65 gunship team sorties. This is the Optimum 2 solution. As can be seen in the diagram, this solution is available only at a higher cost than the first.

Now if the 1678 fighter and attack sorties that were actually flown

ISOQUANT–ISOCOST PRESENTATION

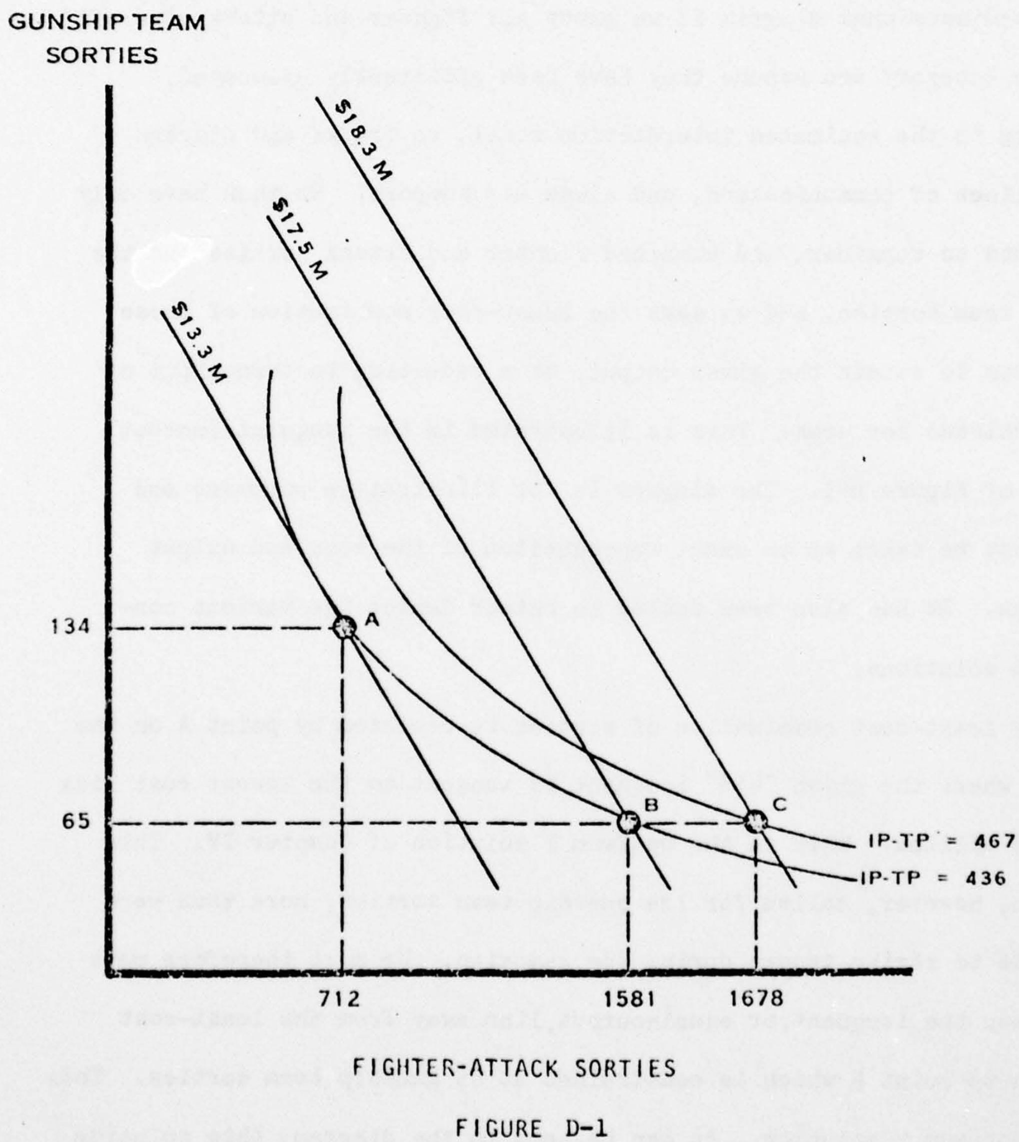


FIGURE D-1

had been efficiently allocated between target types, the potential reduction in throughput would have been 467 truckloads. This solution is point C on the higher "467" isoquant and is the example of maximizing output for a given resource level. The 1678 fighter and attack sorties flown in conjunction with the 65 gunship sorties, however, actually attained a reduction of 436 truckloads. The difference, 31 truckloads, is the reduction in throughput foregone, or the opportunity cost of the inefficient allocation of the fighter and attack aircraft.

On a dollar cost basis,the potential savings available at the Optimum 1 and 2 solutions are the differences between the actual cost line of $18.3 million and the $13.3 million and the $17.5 million lines respectively. The cost overrun, based on the Optimum 2 solution, of attaining a reduction of 436 truckloads was approximately $.8 million, or the cost of the additional 97 sorties flown above the extimated 1581 actually neded. As stated in the body of the text, this overrun amounted to 5 percent of the Optimum 2 cost estimate.

APPENDIX E

COST TABLES

E-1 Variable Sortie Cost by Aircraft Type and Mission

E-2 Attrition Rates and Aircraft/Aircrew Dollar Costs

E-3 Operating Cost Factors for SEA Sorties

TABLE E-1

VARIABLE SORTIE COST BY AIRCRAFT TYPE AND MISSION
(10 October 1970-30 June 1971)

Mission	Type[a] Aircraft	Aircraft Sorties Flown	Aircraft/Crew Attrition Dollar Cost/Sortie	Ordnance and Transportation Dollar Cost/Sortie*	Variable Operating Dollar Cost/Sortie	Total Variable Dollar Cost/Sortie
Strike	F-4 (1.7)	28,437	665	8,540	1,569	10,774
(Includes CAS,	F-100 (1.7)	6,652	148	3,030	1,093	4,271
DAS, Interdic-	F-105 (3.5)	12		3,638	3,420	7,058
tion, MUDY, SAR,	A-1(3.5) SAR	704	1,491	4,400	1,218	7,109
and ARREC but	A-4 (1.7)	7,587		7,510	1,093	8,603
excludes FLAK	A-6 (1.9)	4,430		10,630	1,754	12,384
and SEDY)	A-7 (2.1)	12,909	655	5,670	1,718	8,034
	A-1 (3.2)	188		4,400	1,114	5,514
	AC-130 (4.7)	1,822		7,413	4,808	12,221
	B-57G (1.8)	1,605	3,863	10,598	1,208	15,669
	AC-119 (3.5)	1,181		9,073	1,278	10,351
Sub Total		65,527				
Sensor Delivery	F-4 (1.4)	534	14,419	5,030	1,292	20,741
Sub Total		534				
Gunship Escorts						
and Escort Cover	F-4 (2.9)	6,084	1,353	9,580	2,677	13,600
	F-105 (2.6)	97		3,638	2,540	6,178
	A-1 (3.7)	152		4,400	1,288	5,688
Sub Total		6,333				
Armed Helo						
(Expending)	CH-3 (4.5)	200		2,080	1,661	3,741
	HH-53 (2.0)	329		1,170	1,520	2,690
Sub Total		529				

TABLE E-1 (Continued)

Mission	Type[a] Aircraft	Aircraft Sorties Flown	Aircraft/Crew Attrition Dollar Cost/Sortie	Ordnance and Transportation Dollar Cost/Sortie*	Variable Operating Dollar Cost/Sortie	Total Variable Dollar Cost/Sortie
Arc Light	B-52D (5.0)	5,956		22,080 (66)	7,920	30,000
		1,831		32,508 (108)[b]	7,920	40,752
Sub Total		7,787				
FAC and Flare	OV-10 (4.1)	7,853	323	990	500	1,813
	O-2 (4.0)	5,659	286	780	264	1,330
	F-4 (2.9)	1,355	7,970	165	2,677	10,812
	AC-119 (3.5)	27		108	1,278	1,386
	C-123 (4.5)	742		108	1,616	1,724
	AC-130 (4.3)	139		108	4,399	4,507
	C-130 (3.1)	77		270	2,114	2,384
	B-57G (1.7)	139		108	184	292
Sub Total		15,991				
Recce	F-4 (3.2)	878	4,100		2,954	7,054
	RF-4 (2.2)	3,232	1,112	193	2,385	3,690
	WC-130 (4.9)	264			3,342	3,342
	RF-8 (1.9)	293		200	1,554	1,754
	RA-5 (2.2)	632		400	4,204	4,604
	RB-57 (2.6)	174		414	2,616	3,030
Sub Total		5,473				
Recce Escort	F-4 (2.2)	609			2,031	2,031
	A-1 (3.1)	86			1,079	1,079
	F-8 (1.9)	194			1,554	1,554
Sub Total		889				
Tankers	KC-135 (4.4)	5,672			3,634	3,634
	EA-3 (2.4)	1,152			2,403	2,403
	KC-130 (3.6)	141			2,455	2,455
	A-6 (2.1)	437			1,938	1,938
	A-4 (1.8)	886			1,158	1,158
Sub Total		8,288				

TABLE E-1 (Continued)

Mission	Type[a] Aircraft	Aircraft Sorties Flown	Aircraft/Crew Attrition Dollar Cost/Sortie	Ordnance and Transportation Dollar Cost/Sortie*	Variable Operating Dollar Cost/Sortie	Total Variable Dollar Cost/Sortie
Res Cap	F-4 (1.7)	98			1,569	1,569
	A-1 (3.6)	113			1,253	1,253
	F-100 (2.0)	30			1,286	1,286
Sub Total		241				
SAR and SAR CAP (Not Expending)	F-4 (2.0)	117			1,846	1,846
	C-130 (7.4)	527			5,047	5,047
	A-1 (3.5)	309			1,218	1,218
	HH-53 (3.5)	222			2,660	2,660
Sub Total		1,175				
CAP	F-4 (2.2)	2,569			2,031	2,031
	OV-10 (2.0)	14			244	244
Sub Total		2,583				
MIG CAP	F-4 (2.7)	732			2,492	2,492
Sub Total		732				
Air Aborts Flown	F-4 (1.4)	1,242			1,292	1,292
	AC-130 (2.5)	122			2,558	2,558
	F-100 (1.6)	282			1,029	1,029
	A-1 (2.0)	59			696	696
	AC-119 (2.5)	117			912	912
	B-57G (1.9)	238			1,932	1,932
	Other (1.5)	429			1,200	1,200
Sub Total		2,489				
Psy War	O-2 (4.7)	41			310	310
	C-123 (3.8)	48			1,364	1,364
	C-130 (4.3)	114			2,933	2,933
Sub Total		203				

TABLE E-1 (Continued)

Mission	Type[a] Aircraft	Aircraft Sorties Flown	Aircraft/Crew Attrition Dollar Cost/Sortie	Ordinance and Transportation Dollar Cost/Sortie*	Variable Operating Dollar Cost/Sortie	Total Variable Dollar Cost/Sortie
RDF	EC-47 (6.5)	1,625			1,157	1,157
Sub Total		1,625				
ELINT, ECM and AEW	EA-3 (5.0)	165			5,005	5,005
	E-2 (3.6)	579			641	641
	RA-5 (1.7)	67			3,249	3,249
	EB-66 (3.8)	3,247			3,804	3,804
Sub Total		4,058				
ABCCC and SEMO	C-130 (13.0)	525			8,866	8,866
	EC-121 (11.5)	1,052			12,098	12,098
	QU-22 (5.0)	1,369			500[c]	500
Sub Total		2,946				
Other	F-4 (1.7)	452			1,569	1,569
	A-7 (2.0)	178			1,636	1,636
	A-6 (2.0)	76			1,846	1,846
	RA-5 (1.8)	18			3,440	3,440
	A-4 (1.5)	148			965	965
	F-8 (1.6)	376			1,309	1,309
	HH-53 (3.5)	28			2,660	2,660
	CH-3 (4.5)	59			1,661	11,661
Sub Total		1,335				
Total		128,738				

*Figures in this comumn for recce aircraft represent photographic and development costs.

[a]Figures in parentheses following A/C type are average sortie length in hours for each mission listed.

[b]B-52s flew 60 days in Mar, Apr, and May with a bomb load of 108. There were 1831 sorties flown with this load.

[c]There were few cost figures available for the QU-22. 7/12 AF estimated POL/HR at $4.50 and Material Support at $31.00. Using an O-2 and adjusting, $100/Hr is the estimate used in this table.

TABLE E-2

ATTRITION RATES AND AIRCRAFT/AIRCREW DOLLAR COSTS
(10 October 1970-30 June 1971)

Type A/C	Number of A/C Losses	Mission	Number of Sorties	Aircraft Attrition Rate	Dollar Cost per Aircraft (Millions)	Aircraft Dollar Attrition Cost/Sortie	Crew Attrition Rate	Dollar Cost per Aircraft (Millions)	Aircrew Dollar Attrition Cost/Sortie	Total Dollar Attrition Cost/Sortie
F-4	5	Strike	28437	.000175	3.6*	630.00	.000070	.5	35.00	665.00
	2	Escort	6084	.000328		1188.80	.000328		164.00	1352.80
	1	VR	878	.001139		4100.40	.000000		. .	4100.40
	2	SEDY	534	.003745		13482.00	.001873		936.50	14418.50
	3	FAC	1355	.002214		7970.40	.000000		. .	7970.40
RF-4	1	Recce	3232	.000309	3.6*	1112.40	.000000	.5	. .	1112.40
O-2	4	FAC	5659	.000707	.093	65.75	.000441	.5	220.50	286.25
B-57	1	Strike	1605	.000623	6.2*	3863.00	.000000	.5	. .	3863.00
A-1	2	SAR	704	.002841	.4	1136.40	.001420	.25	355.00	1491.40
OV-10	4	FAC	7853	.000509	.51	259.60	.000127	.5	63.50	323.10
A-7	3	Strike	12909	.000232	2.7	626.40	.000116	.25	29.00	655.40
F-100	1	Strike	6652	.000150	.7	105.00	.000150	.25	37.50	142.50
Total	29									

*Most A/C costs were extracted from AFM 172-3, Table 9A. However, the F-4 and RF-4 costs were taken from Table 9B which listed FY 72-76 cumulative average cost at $3.6 million. The B-57G cost is a PACAF estimate.

TABLE E-3

OPERATING COST FACTORS FOR SEA SORTIES
(10 October 1970-30 June 1971)

*Estimates based on A/C similarity to AF version in parenthesis

	$ Cost per Flying Hour (SEA)						
			Base Maintenance				
A/C--Mission	POL[a]	Depot Maintenance[b]	Base Mater'l Sup't[c]	Civ Labor[d]	Mil Labor[e]	Replenishment Cost[f]	Total Variable Cost/FH[g]
Strike							
F-4	170	228	133	8	252	132	923
F-100	124	163	110	7	218	21	643
F-105	174	281	124	17	279	102	977
A-1	31	130	9	9	88	81	348
A-4* (F-100)	124	163	90	7	218	21	643
A-6* (F-4)	170	228	133	8	252	132	923
A-7	119	267	85	7	210	130	818
AC-130 (20mm only)							858[h]
AC-130SP							1023[h]
AC-130 (UP-PP w/40mm)							1023[h]
AC-119K	65	141	20	13	105	21	365
F-102	87	159	40	19	239	26	570
A-37	46	35	81	2	60	31	255
B-57G	110	223	61	6	202	70	671
FAC and Flare							
OV-10 (Est)	8	31	5	2	53	23	122
O-2A and B	5	9	2	1	38	11	66
F-4 see Strike							
C-123K	86	93	23	4	121	32	359
U-10	5	11	2	1	38	16	73
RF-4	170	228	274	9	271	132	1084
C-130	99	236	47	8	226	66	682
C and EC 47	23	39	14	9	70	23	178

AD-A046 206 AIR FORCE ACADEMY COLO F/G 5/3

AN ECONOMETRIC STUDY OF AERIAL INTERDICTION IN SOUTHERN LAOS, 1--ETC(U)

MAY 77 H L GILSTER, R D DUCKWORTH

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TABLE E-3 (Continued)

A/C--Mission	POL[a]	Depot Maintenance[b]	Base Mater'l Sup't[c]	Civ Labor[d]	Mil Labor[e]	Replenishment Cost[f]	Total Variable Cost/FH[g]
Recce							
RF-4C (see FAC)							
RF-101	162	289	206	9	264	66	996
EB-57	118	610	61	10	162	45	1006
RA-5 (USMC) (F-111)	277	818	168	11	337	300	1911
RF-8 (Navy) (A-7)	119	267	85	7	210	130	818
F-4 (see Strike)							
EC-47 (see FAC)							
EC&WC-130 (See FAC)							
R&EB-66	162	331	160	18	295	35	1001
Arc Light							
B-52D	414	515	283	8	257	107	1584
Tankers							
KC-135	273	226	136	3	107	81	826
Relay							
C-130 (see FAC)							
EC-121	111	227	53	16	203	60	670
RC-135	265	246	137	5	158	81	892
QU-22 (Est)	5	9	31	1	43	11	100
SAR							
HH-53	44	154	30	15	117	400	760
UH-1	8	30	9	5	74	18	144
CH-3	21	84	30	15	117	102	369
H-43	8	70	10	11	83	90	272
Cargo							
C-7	28	60	8	5	88	33	222

TABLE E-3 (Continued)

[a]Figures in this column represent aircraft fuel and oil cost per flying hour based upon data in AFM 172-3, USAF Cost and Planning Factors, Table 11, pp. 11-2 to 11-4. The figures in AFM 172-3 were increased by 18 percent to allow for consumption in a hostile environment. This increase is recommended in AFM 172-3, p. 11-1.

[b]Depot Maintenance was extracted directly from AFM 172-3, Table 12A, pp. 12-9 to 12-11.

[c]Systems and General Support figures (FY 72 Operations Operating Budget Areas 605 and 609) were taken from AFM 172-3, Table 12B from the PAC command column.

[d, e]Civilian and military labor costs were taken from the worldwide figures reflected in AFM 172-3, Table 12A. Basically AFM 172-3 figures were derived by using a cost per manhour factor of $6 to $9.

[f]Replenishment spares cost per flying hour factors were extracted directly from AFM 172-3, Table 12D, pp. 12-15 to 12-17.

[g]Total Variable Cost/FH is the summed total of the previous seven columns. It was developed using the factors in AFM 172-3 adjusted by commands (PAC) for actual SEA experience. The use of these inputs to compute variable costs corresponds to the method followed in USAF Management Summary, Reference Data Section, footnote 1, pp. 8, 9, 10 and 11.

[h]The AC-130 operating and maintenance cost/FH was based on the C-130 cost taken from AFM 172-3 plus 25 percent added for the systems. The Surprise Package, Pave Pronto and Update versions were given an operating and maintenance cost/FH that was 50 percent higher than the C-130 cost/FH. These increases correspond with previous CINCPAC estimates.

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